

AN INVESTIGATION OF MERCURY AS A  
HIGH-SPEED ELECTRICAL CONTACT

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R. G. SHULTS

THESIS  
S49

1911  
The National Protestant School  
Monterey, California









This work is accepted as fulfilling the  
thesis requirements for the degree of Master  
of Science in Electrical Engineering from the  
United States Naval Postgraduate School.





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By

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Commander, United States Navy

SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE

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Preface

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The use of carbon as a medium for transferring electrical currents between two pieces of copper moving at different, and often high, relative speeds is a long-established and adequately successful practice; that is, it is a practice successful at sea level and at the lower altitudes. The growth of the electrical load in aircraft, coupled with its ability to reach ever-increasing altitudes has led to failure of the standard carbon brushes. The reasons for the failure of carbon brushes at high altitudes are not well known, but are believed due to the deterioration of the lubricating qualities of standard air at the higher altitudes. The nature of the carbon brush failure is an accelerated wearing away of the brush in a matter, sometimes, of minutes, whereas at sea level it might have lasted for years at the same speed and current density.

In recent months much has been done to increase the life of the carbon brush at high altitudes. One manufacturer reports a specially impregnated carbon brush with a high altitude life of some 750 hours. On the other hand, certain of the steps taken to make the carbon brush more durable at high altitudes have rendered it short-lived at the lower

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altitudes. A comprehensive review of the high-altitude carbon brush-dusting problem may be found in Ref. 1.

As a partial answer to the problem, this investigation was initiated. Reasoning was along these lines: If a solid type of brush is troublesome, could a liquid type, of necessity enclosed, be designed to be less troublesome? The liquid, of course, should be a good conductor, should be easy to handle and contain, should be readily available, but need not necessarily be inexpensive if it could eliminate electrical power failure in modern military aircraft now caused by carbon brush dusting.

A good many fluid conductors of electricity immediately suggested themselves, but one of the best and most common, the fluid metal mercury, was almost an obvious first choice, particularly since Faraday had suggested its use in connection with the homopolar machine (see Ref. 2).

As a first step then, in August 1951 an idea for a test vehicle was sketched and presented to Professor C. V. O. Terwilliger, Head of the Electrical Engineering Department of the U. S. Naval Postgraduate School, then at Annapolis, Maryland. Dr. Terwilliger considered the idea worthy of thesis investigation as part of the requirements leading to the award of a Master's Degree in Electrical Engineering. Consequently, the device was designed and built at Annapolis, being completed by mid-November 1951.

Due to the moving of the Postgraduate School to Monterey, California in late November 1951, actual testing was delayed

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until April 1952. The nature of the testing and the results obtained are herein set forth.

It is at once apparent that a fluid brush would not be compatible with a commutator; hence, it was considered only for its use with a slip-ring. In this connection, then, one must keep in mind that even though the fluid brush might be successful in solving the high-altitude brush problem, it would eliminate the commutator and make necessary the employment of the homopolar machine either for main direct current generation or for dc excitation for the alternator. Thus, a secondary problem arose requiring investigation: could the extra weight and size, if any, of the homopolar machine be tolerated?

Because time ran out and because this investigation and a report of it had of necessity to be completed by June 1952, the mercury brush was little more than made ready for a sea-level test and the secondary problem was not approached at all.

Thus there remains considerable investigation at sea level, and the total investigation in an altitude chamber, plus any flight testing which might ultimately be indicated.

It follows that the success or failure of mercury need not preclude further investigation of the many other fluid conductors, nor of the homopolar generator as an exciter, for other reasons.

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*R. A. Shultz*

June, 1952  
 Monterey, California  
 U. S. Naval Postgraduate School  
 Section AED  
 CDR R. A. Shultz, USN

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Summary

In seeking a possible substitute for the carbon brush for aircraft use, the idea of using mercury as a fluid contact was investigated.

It was found that a mercury-steel combination appeared to be satisfactory electrically at sea level.

It was further found that the voltage drop across the moving mercury-steel contact appeared to be *independent* of the current flow through the contact and of the relative speed of the contact surfaces.







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AN INVESTIGATION OF  
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Equipment

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A fluid conductor brush must take the general form of two solid conductors separated by the fluid in order to permit relative motion. A typical usage would find one of the solid conductors fixed; the other moveable. While an experimental design along these lines would have been preferred as simulating actual conditions more closely, but because it was desired that its performance at high peripheral speeds be known, the mercury brush was designed so that both solid conductors could move in opposite directions. This led to unsatisfactory operating conditions at high speeds as will be pointed out later.

Consequently, the test mercury brush as built took the form of a steel disc rotating in a pool of mercury contained in a steel cylinder rotating in the opposite direction. The use of steel in the presence of mercury was again an almost obvious first choice, since mercury dissolves all common metals as amalgams except iron, platinum and nickel.

Concerning the size to make the test brush there was little to go on, and it was decided to keep it fairly small since if it should bust for any reason, the danger to those



about it would be greatly minimized. As a further consideration, ready-made drive shafting and matching bearings with pedestals were immediately available and were of such size that a large mercury brush was inadvisable. In order to further reduce danger due to busting, the walls of the cylinder were made much thicker than necessary. This also led to an operational problem to be pointed out later.

It was necessary to provide some sort of seal about the entering disc shaft to prevent any tendency for the mercury to leak. This took the form of a close-fitting machined-pressed paper insert, screwed to the cylinder face. This, too, proved a troublesome spot until late in the test period.

To provide for interim inspection of the interior of the brush, the shell of the cylinder was made so that it could be unscrewed and the disc withdrawn. This feature also proved a problem at high speeds and although never solved in this series of tests, its solution would be no problem in future tests, as will be pointed out.

Since mercury boils at sea level at about 356.9° C. and since it was not known what the heat generation might be in the brush, it was thought necessary that some means of recording temperature be provided. This was effected by drilling out the center of the two drive shafts to permit insertion of thermometers. This feature proved very helpful and gave no trouble directly, although it contributed to a hot-spot





problem, as will be pointed out. The sensitive elements of the thermometers were thus placed almost at the center of the brush.

To provide a means of driving the two elements of the brush, two 4-step cone pulleys were mounted on the shaft to be belt-driven by two D.C. motors. These motors were Marathon Electric 1/8 HP, shunt-wound, 115 V, 1.3a, 1725 rpm, type DS motors. To provide speed control in addition to that inherent in the pulleys, rheostats, 100 ohms and 800 ohms, respectively, were placed in both armature and field circuits of the driving motors. This feature permitted excellent speed control throughout the test period.

To get current to the mercury brush since it was not a part of any sort of generating device and because both parts of it rotated, it was necessary to resort to carbon brushes and brass slip rings--brass because copper was not available and because the phenomena occurring at the carbon brushes would have no effect on the mercury brush anyway. To this extent, a sort of loose comparison of the two brushes unfolded as they operated side-by-side under identical conditions during the tests. Carbon brushes and holders were salvaged from an aged surveyed repulsion-induction motor and a mounting bracket of bakelite was fashioned to permit two carbon brush sets to operate in parallel on each of the two brass slip rings. This arrangement proved entirely satisfactory.

The apparatus in its entirety was mounted on a large steel plate to provide dimensional stability and mechanical damping.



This, too, was most satisfactory. It was at once obvious, however, that if the drive shafts were to be current conductors, insulation from this steel plate was necessary. This was easily accomplished by mounting the bearing pedestals on pressed paper, by mounting the pulleys on pressed paper sleeves, by using non-conducting v-belts, by setting the carbon brush holders in bakelite as already mentioned and by using insulating tape to keep the thermometers from rotating. At no time during the tests did grounds develop.

To provide a uniform length of path for current flow through the mercury, the disc edge was made circular in cross-section and the interior of the cylinder was so machined that the distance from the disc to the cylinder was  $1/8$ " in all directions. There was no particular reason for this gap length; further tests would surely establish an optimum.

The test mercury brush as described thus far was designed by the investigator and built by Mr. Joseph Octavek of the Machine Shop Section of the Postgraduate School. It must be pointed out here that the failures which occurred were faults of design, whereas the ability of the device to withstand testing as it did was a credit to the great care which Mr. Octavek exercised in putting the device together. The drawing from which it was built and assembled appears as Fig. 1, placed at the back of the report because of its large size. A close-up photograph of the brush assembly is shown by Fig. 2.



Although the Postgraduate School resumed classes in February 1952, tests were delayed because of lack of power at the laboratories. When 3-phase AC power did become available, DC power also became available from any one of a number of motor-generator sets in the laboratory. This was thus the source of power. Voltage for the driving motors was taken from the house DC bus. An independent M-G set was operated to supply DC power to a standard load resistor bank which was fed through the test brush assembly. In this way, variation of load on the test brush could have no effect on the driving motor voltage and thus made for better speed control as well as load control.

The load resistor bank consisted of three separate banks, each of 24 amperes capacity at 125 volts, connected in parallel to provide up to 72 amperes. The generator feeding the load bank was rated at 110 volts, 59 amperes. To keep the carbon brush current density below 50 amperes per square inch, no more than 48 amperes were ever fed through the brushes.

To provide forced ventilation since the presence of mercury vapor was a distinct possibility, two ordinary 18" fans were provided. It later developed that by placing one of the fans quite close to the brushes, enough cooling was provided to permit extension of the tests.

In addition to the thermometers, which were Weston Model 226 calibrated from 0 degrees C. to 200 degrees C., other measuring devices were provided as follows.



To measure rotary speeds of each pulley, two Strobotacs were mounted to flash continuously and directly on the pulleys as shown by Fig. 3, Serial No. 16611 was directed on the disc pulley; Serial No. 16756 on the cylinder pulley. The Strobotacs were of two speed ranges: 600 to 3000 rpm and 2400 to 15000 rpm.

To measure brush current, a Weston Model 45 DC ammeter Serial No. 59320, scale 0 to 50 amperes was placed in series with the brushes. Its calibration curve is given by Fig. 4.

Mercury brush voltage was taken with a General Electric 100,000 ohms per volt DC voltmeter, Serial No. 1112214, scale 0 to 3 volts, whose calibration curve appears as Fig. 5. Picking off the voltage drop across the mercury brush was something of a problem never satisfactorily solved, as will be discussed. Pickoff was provided by two thin brass leaves riding on the inside faces of the two brass slip rings, as shown at points A in Fig. 2.

For no particular reason other than to provide information for the previously mentioned loose comparison of the performance of the carbon brush vs. that of the mercury brush, the drop across the entire brush assembly; i.e., the carbon and mercury in series, was taken by a Westinghouse 5000 per volt DC voltmeter, Serial No. 2357120, scale 0 to 10 volts. Calibration curve for this meter is given by Fig. 6.

The load voltage applied to the brushes was taken by a Westinghouse 5000 ohms per volt DC voltmeter, Serial 2357110, scale 0 to 500 volts. This meter was not calibrated.

Two side views of the complete test assembly are given by Figures 7 and 8. A steel shield, not shown, was provided





to cover the rotating parts during the test--it proved necessary. It did not restrict air-flow from the fans.



## PROCEDURE

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The period 22 April 1952 through 11 May 1952, ten working days, was consumed in readying the device for test. Twenty-three formal tests in which data were taken were conducted from 12 May 1952 through 26 May 1952, actual tests being made on only ten working days of this period. A log of the entire experiment was kept and is included herein as Appendix A.

Test procedure was simple enough. Only three quantities, in general, were permitted to vary. These were:

- (1) Brush Current
- (2) Brush Relative Speed
- (3) Mercury Volume (and hence current density in the mercury)

For each test, readings were recorded of brush load supply voltage and current, voltage drop across the entire (carbon in series with mercury) brush assembly, voltage drop across the mercury brush alone, rpm of each shaft, and temperature at the centers of the disc and of the cylinder. Beginning with Test No. 11, elapsed time readings were taken along with all other readings.

For tests No. 11 through 23, one of the 18" fans was moved to within 12" of the mercury brush as shown clearly by Fig. 3, providing, it was estimated, some one or two inches of water blast air cooling.



For Tests No. 1 through 19, the mercury level was maintained at what is designated herein as Level A. Level A was that created by the placing of about 15.5 cc of Hg in the cylinder, whose capacity to contain 100% mercury was computed as 21.5 cc. This, depending on how one considered the displacement of the mercury during rotation, gave rise to a contact area on the disc (the minimum) of 6.11 or of 7.80 square inches.

The mercury level was reduced to Level B for Tests No. 20 and 23. This level provided an estimated minimum mercury contact of 3.63 square inches.

Tests No. 21 and 22 were conducted at Level C, which furnished a minimum mercury contact area of some 1.45 square inches.

As mentioned previously, maximum current ever passed through the brush was 48 amperes, which amount to 50 amperes per square inch through the carbon brushes. Actually, the carbon brushes functioned very well, but to prevent any loss of test time due to failure of the carbon brushes, old, of peculiar size and whose composition was unknown, it was decided to set this limit. On the other hand, 48 amperes represented a reasonable load on the rated 59-amperes generator which had just made a transcontinental trip; also the breaker was set for 50 amperes.

A graphical presentation of current density variation is given by Fig. 9, based upon the above calculations of



minimum mercury contact area.

For tests No. 1 through 18, the cylinder was the positive (+) terminal; for tests No. 19 through 23, the disc was the positive terminal.

For tests No. 1 through 18, the carbon brush pressure was the maximum (actual value not determined); for tests No. 19 through 23, the carbon brush pressure was the minimum (actual value not determined).

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RESULTS &  
DISCUSSION

TABLES

ILLUSTRATIONS

APPENDIX

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RESULTS &  
DISCUSSION

## RESULTS

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Of the 23 tests, the first four were excluded from consideration on the basis that they were conducted at speed levels below that of interest. The first four tests were intentionally so conducted in order to permit observation of the test device in operation as designed before the higher speeds were attempted.

The data taken as listed under the Procedure Section was put into tabular form; certain derived factors added; certain averages taken and included herein as Tables I through XV. Current densities both for the carbon and mercury were computed, as was the carbon brush drop. A curve of current densities, already mentioned, appears as Fig. 9. Also computed was the relative speed of the cylinder surface in contact with the mercury with respect to the disc surface in contact with the mercury and moving in the opposite direction. This amounted simply to the sum of the separate peripheral velocities of the two respective surfaces. Figures 10 and 11 show in convenient graphic form the relation between rpm and peripheral velocity as function of diameter.

It is important that the manner of taking the brush drops be noted. Due to the rather poor contact made by the carbon brushes and by the brass spring leaf pickoff's, these two voltages fluctuated through easily detectable ranges as much as 0.2 to 0.4 of a volt. Thus the data recorded in



The first part of the report  
 describes the general situation  
 of the country and the  
 progress of the work  
 during the year.  
 The second part  
 contains the results of the  
 investigations and the  
 conclusions drawn from them.  
 The third part  
 contains the financial statement  
 and the balance sheet.  
 The fourth part  
 contains the annual report  
 of the directors.  
 The fifth part  
 contains the annual report  
 of the shareholders.  
 The sixth part  
 contains the annual report  
 of the creditors.  
 The seventh part  
 contains the annual report  
 of the employees.  
 The eighth part  
 contains the annual report  
 of the public.  
 The ninth part  
 contains the annual report  
 of the government.  
 The tenth part  
 contains the annual report  
 of the world.

Tables I through XV reflect the observer's opinion of the value the two meters were attempting to indicate, and may therefore be in error to some extent. This was not true of many readings, however, and in all cases readings were observed long enough (as long as several minutes in some cases) to reasonably establish the mean indication.

In addition to the tabular reduction of the recorded data, certain graphical plots were prepared.

Fig. 12 is a plot of the drop across the mercury brush as a function of contact speed for three different currents for Tests No. 5 through 19. Its source was Tables I through XII.

Fig. 13 shows the same information, plotted on a smaller scale, as Fig. 12, plus the addition of Tests No. 20 through 23, plus the addition of heat rise information on these 19 tests. The additional information was obtained from Tables XVI and XVII. The plotted temperature rise, Table XVII, was the average of the two thermometer indications.

Fig. 14 is a plot of the mercury brush drop as a function of brush current for several different relative speeds. Its source, as well, lies variously in Tables I through XV.

Finally, Fig. 15 is a plot (of Test No. 21 only) of the mercury brush drop vs. time at 10,350 rpm relative (107 f.p.s. relative). This was the greatest speed attained: for various reasons, to be pointed out, greater speeds with the test device in its present form were not possible. Fig. 15

100

100

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also shows the temperature variation of both disc and cylinder throughout the test. This Test No. 21 was the most thoroughly conducted of all tests, it is believed, and for that reason it was plotted separately. In retrospect, all tests should have been similarly conducted, but as mentioned earlier, the experiment really only reached the point for good testing when it had to be stopped for want of time. Test No. 21 is tabulated in Table XIV.





## DISCUSSION

A good understanding of the defects and shortcomings of the test device is a first requisite in evaluating the results obtained. These deficiencies have been raised variously throughout the report.

For the first series of tests; that is, No. 1 through No. 19, the mercury level was the greatest used. In turn, for these tests, current density was least. It was first thought such a volume of mercury would lead to best results, but this was not the case. As the higher rpm were approached three objectionable features became apparent.

The first to be noticed was the high heat generated on the rim of the cylinder due to nothing more than friction. This, in turn, led secondly to expansion of the cylinder and at 3000 rpm absolute, the combination of heat and centrifugal force was enough to permit a fine spray of mercury to be thrown out through the threaded joint by which the two pieces of the cylinder were joined. The canopy shielding the rotating parts proved essential here.

The third objection to the high level of mercury was again mechanical. The oppositely rotating disc seemed to "roll up" the mercury between it and the cylinder. This led to unbalance which at the higher rpm created heavy vibration in the device.



From the heat standpoint, there were two other defects. The walls of the cylinder were  $1/4$ " thick; probably thicker than they need have been by perhaps as much as  $3/16$ ". These thick walls, without cooling fins, simply could not radiate heat efficiently enough. Also, since an arbitrary maximum temperature on either thermometer had been established as  $100^{\circ}\text{C}$ , an unnecessary limitation was imposed by the fact the  $5/16$ " shaft had to be provided with a  $5/32$ " core to permit insertion of the thermometers. At the point where the cylinder was screwed on to its shaft, there were two or three threads which did not go fully into the cylinder. This combination of a drilled-out center and exposed exterior threads created a hot spot due to current flow through the very narrow cross-section at this point. It was thus always a question with just what share of the heat was the mercury to be credited. This hot spot is indicated as "B" in Fig. 2.

Another hot-spot problem arose where the pressed-paper seal raced on the disc shaft.

Accordingly, three steps were taken to remedy the above problems. To alleviate the hot-spot at the thin cross-section of the cylinder shaft, a bead of solder was laced about the shaft at "B" of Fig. 2. To reduce heat due to friction within the mercury, the mercury level was reduced (see Fig. 9). To reduce the hot-spot at the seal, it was removed and part of it filed away.

When the device was re-started, it was at once apparent too much of the seal had been removed, but it



coincidentally gave opportunity to note the nature of the turbulence in the mercury. It had been thought centrifugal force was holding the mercury smoothly away from the center and that the seal was not really needed. Actually, there must have been terrific turbulence in the mercury if the degree of leakage through the seal was any index. It was also interesting to note the leaking out the seal could be stopped by speeding up the cylinder. This led to a restoration of the seal and a further reduction of the mercury level.

Now, upon re-starting, improvement over initial operating conditions was clearly noted. It was possible now to run the device up to 10,350 rpm relative, and indications were higher peripheral velocities could be obtained.

There was some trouble with voltage pickoff across the mercury brush. At first it had been intended to take this voltage through the bearings. This was a futile proceeding; no voltage indication where voltage was known to be. It was clear after the situation presented itself that the bearing grease was acting as an insulator. The answer was to take the voltage off two brass spring leaf probes riding on the side of the brass slip rings. Even these gave fluctuating voltage readings, though great improvement was attained simply by smudging the pickoff race with carbon.

It was because of these pickoffs that ohmmeter readings were not taken seriously. Whereas some contact resistance at the probes would have little effect on the

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100,000 ohms per volt voltmeter being used, they were thought possibly to show a good deal more resistance than would the mercury. Ohmic readings ran anywhere from 16 ohms to 60 ohms measured across the pickoff's during rotation; at standstill, readings were variously 2 to 5 ohms. The ohmmeter was used mainly to insure a closed circuit through the brush before loading it electrically, as otherwise the full supply voltage would have appeared across the 3-V voltmeter.

In this connection, one inadvertent open-circuit did develop across the mercury brush. Test No. 22 followed Test No. 21 very closely, the first being at 10,350 rpm relative; the second at 6,000 rpm relative. Obviously enough, mercury was thrown from the cylinder at 10,350 rpm almost to deplete it. At the end of Test No. 22 (do see Table XV) during which there was no leakage, when the current was dropped from 25 amperes to only 5 amperes, the brush voltage dropped from 0.35 volt to 0.05 volt and this voltage could be repeated by shutting the current on and off, 0 to 5 amps. Curious over this, speeds were increased toward 10,000 rpm again which immediately opened the circuit at the mercury brush. From this, it appeared that there does exist an optimum minimum mercury volume, or conversely, an optimum maximum current density. It should be obvious here that Fig. 9 is very probably in error concerning Tests No. 21 and 22. Time did not permit looking

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into this interesting occurrence any further. It does appear such optimum should be sought and great pains taken to prevent any leaking so that good quantitative information could be obtained.

With this much background, it is now clear to the reader that any observations to be made concerning the experiment should be qualitative only, in spite of the rather formidable mass of data taken.

Fig. 12, a plot of mercury brush voltage drop vs. contact speed, would indicate that the drop increased both with contact speed and current density. However, it may actually be that the drop is independent of either current density or contact speed, and is rather dependent on heat only, since both increase in current density and in contact speed lead to heat generation. It is well known that resistance of metallic conductors increases with temperature. The drop being measured was not strictly across just the mercury. Actually, the drop was being measured across part of each brass slip ring, across about 4" of steel shaft of very narrow cross-section, and across the steel disc and cylinder, all of which became heated along with the mercury.

Fig. 13 seems to indicate a temperature effect rather than a speed or current density effect. Tests No. 20 through 23 were run after the remedial heat-reducing steps discussed earlier were taken. Fig. 13 shows a decrease in voltage drop across the mercury brush for the last four tests as compared to the previous fifteen. For the last four tests, current density was greater than during the previous fifteen and speeds were greater.

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With this as a basis, it is now clear that the pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid.

Fig. 1, a diagram of a mercury barometer, shows the pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid.

and is rather dependent on the density of the gas. The pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid.

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Fig. 12, a diagram of a mercury barometer, shows the pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid.

run after the preceding test of the pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid. The pressure in the gas is not affected by the presence of the liquid.

Fig. 14 would also appear to support the above opinion. In Fig. 14 the drop across the mercury brush is plotted against current. Here again it may be seen that by reducing the heat generated (Test No. 21), the voltage drop was less at 10,350 rpm than at 6,000 rpm for Test No. 14.

A comparison of Test No. 22 at 6,000 rpm, Table XV, with Test No. 25 at 10,350 rpm, Table XIV, both at about the same current density and both showing similar temperature rises, would appear to indicate the decrease in voltage drop of Test No. 22 was speed motivated.

A comparison of Test No. 22 at 6,000 rpm of high current density with Test No. 14, Table X, at low current density, would seem to show the decrease in voltage drop of Test No. 22 was current density motivated.

None of the effects on the voltage drop across the mercury brush were of great magnitude, however. The voltage drop varied from a minimum (excluding the point at 0.05 volt) of about 0.5 volt at 3,000 rpm relative to a minimum of about 0.7 volt at 10,350 rpm relative.

Although a comparison of the mercury brush against the carbon brush would not be fair in this test, an examination of the data sheets will show the carbon drop to be consistently higher. The carbon brush drop tabulated is that for two carbon brushes in series.

Though not under investigation, the carbon brushes did show some interesting (and well known) characteristics. It was observed that when current was reduced suddenly the



carbon brush drop would decrease as suddenly to about one-quarter of its original value. Within a few minutes at the reduced current, the carbon voltage drop would build back to its original value. It was also easy to observe the fact that there was less drag of the carbon brushes on their slip rings when current was flowing than when running on open circuit. The carbon brush drop also increased as brush pressure decreased.

Pure mercury was used in this experiment. At no time did any of the leakage mercury appear to have oxidized or to show any other change in appearance. The possibility of a change in the mercury with age in the brush is not being overlooked; a life-test is indicated here. Also, the effect of the mercury on the container with time should be examined. In this connection the addition of a slight amount of titanium<sup>u</sup> or zirconium to mercury is said to completely inhibit its attack on steel. Also, a better wetting of the steel surface by the mercury is claimed to be effected by the presence of a tiny amount of magnesium. These and other facts about mercury appear in Appendix B as excerpts from Ref. 3. Some of the physical properties of mercury are given in Table XVIII.

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Ret. 3. Some of the results of the experiment  
given in Table III.

## CONCLUSIONS

The word "conclusion" carries with it too final a ring for this experiment as thus far conducted. Perhaps some opinion can be expressed.

1. A mercury brush is a satisfactory device electrically at sea level.
2. The voltage drop induced by current flow across a moving mercury-steel contact is independent of current density and speed of contact.





## RECOMMENDATIONS

These recommendations could concern only those who might be interested in pursuing the project further along similar lines.

1. The "disc" should be fixed and only the "cylinder" rotate.

2. Some sort of variable-speed drive up to 12,000 rpm would be useful.

3. The cylinder diameter should be increased progressively to permit investigation up to an absolute maximum peripheral speed.

4. The use of the liquid conductor brush on an actual machine would serve to eliminate the carbon brushes.

5. Drive shaft size should be kept large enough to obviate heat generation due to current flow in it.

6. It would be desirable to build into the device some sort of plastic window to permit visual observation of the phenomena occurring.

7. The means of picking off the voltage drop across the brush should be improved.

8. The effect of varying the gap length shorted by the liquid conductor should be investigated.

9. The effect of varying the contact area (current density) needs further investigation.

- These observations are of interest in connection with the following points:
1. The effect should be of the same order of magnitude as the effect of the other factors.
  2. Some sort of variation in the effect of the other factors would be expected.
  3. The effect of the other factors should be of the same order of magnitude as the effect of the other factors.
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  9. The effect of the other factors should be of the same order of magnitude as the effect of the other factors.

10. The liquid conductor container should be seamless in the region where the fluid will circulate during rotation.

11. An effective seal against leakage about the "disc" shaft is an essential.

12. The test data to be taken should be given careful consideration and every test identically conducted.

13. A life-test of the device should be conducted after which a critical examination of the contact surfaces and the fluid conductor should be made.

10. The third component of the test is

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rotation.

11. An objective test is one in which

shift is essential.

12. The test is one in which the

consideration of the test is

13. A test of the test is one in which

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faces and the test is one in which

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APPENDIX

ILLUSTRATIONS

TABLES



No. 4780SI  
Colored Tabs  
No. 4781SI  
Clear Tabs

MADE IN U. S. A.

NATIONAL INSERTABLE-TAB INDEXES ENABLE YOU TO  
MAKE YOUR OWN SUBJECT ARRANGEMENT, USING PLAIN  
INSERTS ON WHICH TO WRITE YOUR OWN CAPTIONS.



TABLE I  
RESULTS OF TEST NO. 5

Start Test No. 5 @ 1400; Stop @ 1430

RPM, disc. . . . .900

RPM, cylinder. . . . .600

Speed, relative, f.p.s. . 15

Ambient temp, °C . . . . 29

Date . . . . .15 May 1952

Brush Current, Amperes	Carbon Current Density Amp/In <sup>2</sup>	Mercury Current Density Amp/In <sup>2</sup>	Total Brush Drop Volts	Carbon Brush Drop Volts	Mercury Brush Drop Volts	* Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp. Rise °C
4	4.26	.65	2.35	1.89	.46	5	7	8
8	8.52	1.31	2.75	2.31	.44	7	8	10
12	12.78	1.96	2.80	2.36	.44	9	9	12
16	17.04	2.52	2.90	2.40	.50	12	9	14
20	21.33	3.27	3.10	2.64	.46	14	13	17
24	25.56	3.93	3.10	2.58	.52	17	14	21
28	29.82	4.58	3.20	2.66	.54	19	17	25
32	34.08	5.24	3.30	2.73	.57	21	19	31
36	38.34	5.89	3.40	2.84	.56	22	22	36
40	42.66	6.55	3.45	2.85	.60	23	25	40
44	46.86	7.20	3.60	2.99	.61	24	29	44
48	51.15	7.85	3.80	3.17	.63	25	32	49
48	51.15	7.85	3.75	3.09	.66	30	#49	#69

\*Approximated on basis of later timed tests.

#Temperature stabilized.

# TEST RESULTS OF TEST NO. 1

Start Test No. 1 1000; 1000; 1000

1000 . . . . . RPM, 4th  
 1000 . . . . . RPM, 5th  
 1000 . . . . . RPM, 6th  
 1000 . . . . . RPM, 7th  
 1000 . . . . . RPM, 8th

Brush Current, Amperes	Current Density, A./sq. in.	Terminal Voltage, Volts	Internal Voltage, Volts	Field Voltage, Volts	Armature Voltage, Volts	Field Current, Amperes	Armature Current, Amperes	Power Consumption, Watts	Efficiency, %
4	4.00	1.40	0.95	0.45	0.45	0.45	0.45	1.80	100
8	8.00	1.31	0.87	0.44	0.44	0.44	0.44	3.60	100
12	12.00	1.22	0.79	0.43	0.43	0.43	0.43	5.40	100
16	16.00	1.13	0.71	0.42	0.42	0.42	0.42	7.20	100
20	20.00	1.04	0.63	0.41	0.41	0.41	0.41	9.00	100
24	24.00	0.95	0.55	0.40	0.40	0.40	0.40	10.80	100
28	28.00	0.86	0.47	0.39	0.39	0.39	0.39	12.60	100
32	32.00	0.77	0.39	0.38	0.38	0.38	0.38	14.40	100
36	36.00	0.68	0.31	0.37	0.37	0.37	0.37	16.20	100
40	40.00	0.59	0.23	0.36	0.36	0.36	0.36	18.00	100
44	44.00	0.50	0.15	0.35	0.35	0.35	0.35	19.80	100
48	48.00	0.41	0.07	0.34	0.34	0.34	0.34	21.60	100
52	52.00	0.32	0.00	0.33	0.33	0.33	0.33	23.40	100
56	56.00	0.23	0.00	0.32	0.32	0.32	0.32	25.20	100
60	60.00	0.14	0.00	0.31	0.31	0.31	0.31	27.00	100
64	64.00	0.05	0.00	0.30	0.30	0.30	0.30	28.80	100
68	68.00	0.00	0.00	0.29	0.29	0.29	0.29	30.60	100
72	72.00	0.00	0.00	0.28	0.28	0.28	0.28	32.40	100
76	76.00	0.00	0.00	0.27	0.27	0.27	0.27	34.20	100
80	80.00	0.00	0.00	0.26	0.26	0.26	0.26	36.00	100
84	84.00	0.00	0.00	0.25	0.25	0.25	0.25	37.80	100
88	88.00	0.00	0.00	0.24	0.24	0.24	0.24	39.60	100
92	92.00	0.00	0.00	0.23	0.23	0.23	0.23	41.40	100
96	96.00	0.00	0.00	0.22	0.22	0.22	0.22	43.20	100
100	100.00	0.00	0.00	0.21	0.21	0.21	0.21	45.00	100

\* Efficiency = (Output Power / Input Power) x 100  
 Efficiency = (21.60 / 23.40) x 100 = 92.3%

TABLE II  
RESULTS OF TEST NO. 6

Start Test No. 6 @ 1445; Stop @ 1515.

RPM, disc. . . . . 1300  
RPM, cylinder. . . . . 700  
Speed, relative, fps. . . 20  
Ambient temp, °C . . . . 30  
Date. . . . . 15 May 1952

Brush Current, Amperes	Carbon Current Density Amp/In <sup>2</sup>	Mercury Current Density Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	* Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp. Rise °C
5	5.33	.82	2.35	2.03	.32	5	17	13
10	10.66	1.64	2.65	2.30	.35	8	17	13
15	16.00	2.46	2.80	2.46	.34	11	17	15
20	21.33	3.27	3.10	3.08	.32	14	18	20
25	26.66	4.09	3.15	2.80	.35	17	19	23
30	32.00	4.91	3.20	2.88	.32	19	21	26
35	37.33	5.73	3.20	2.82	.38	21	23	30
40	42.66	6.55	3.35	2.97	.38	23	25	33
45	48.00	7.36	3.45	3.05	.40	24	28	39
48	51.15	7.85	3.60	3.22	.38	25	31	44
48	51.15	7.85	3.80	3.36	.44	30	#45	#63

\*Approximated on basis of later timed tests.

#Temperature stabilized.

U.S. DEPARTMENT OF AGRICULTURE

State test year: Fall 2007

[illegible]

Brush Current, Amperes	Brush Current, Volts	Brush Current, Watts	Brush Current, Amps	Brush Current, Volts	Brush Current, Watts	Brush Current, Amps	Brush Current, Volts	Brush Current, Watts	Brush Current, Amps	Brush Current, Volts	Brush Current, Watts
5	10	50	10	15	150	20	20	400	25	25	625
10	15	150	20	20	400	25	25	625	30	30	900
15	20	300	30	25	750	35	35	1225	40	40	1600
20	25	500	40	30	1200	45	45	2025	50	50	2500
25	30	750	50	35	1750	55	55	3025	60	60	3600
30	35	1050	60	40	2400	65	65	4225	70	70	4900
35	40	1400	70	45	3150	75	75	5625	80	80	6400
40	45	1800	80	50	4000	85	85	7225	90	90	8100
45	50	2250	90	55	4950	95	95	9025	100	100	10000
50	55	2750	100	60	6000	105	105	11025	110	110	12100
55	60	3300	110	65	7150	115	115	13225	120	120	14400
60	65	3900	120	70	8400	125	125	15625	130	130	16900
65	70	4550	130	75	9750	135	135	18225	140	140	19600
70	75	5250	140	80	11200	145	145	21025	150	150	22500
75	80	6000	150	85	12750	155	155	24025	160	160	25600
80	85	6800	160	90	14400	165	165	27225	170	170	28900
85	90	7650	170	95	16175	175	175	30625	180	180	32400
90	95	8550	180	100	18000	185	185	34225	190	190	36100
95	100	9500	190	105	19875	195	195	38225	200	200	40000
100	105	10500	200	110	21800	205	205	42225	210	210	44100
105	110	11550	210	115	23875	215	215	46225	220	220	48400
110	115	12650	220	120	26000	225	225	50225	230	230	52900
115	120	13800	230	125	28275	235	235	54725	240	240	57600
120	125	15000	240	130	30600	245	245	59725	250	250	62500
125	130	16250	250	135	33075	255	255	64725	260	260	67600
130	135	17550	260	140	35600	265	265	70225	270	270	72900
135	140	18900	270	145	38275	275	275	75725	280	280	78400
140	145	20300	280	150	41000	285	285	81225	290	290	84100
145	150	21750	290	155	43875	295	295	86725	300	300	90000
150	155	23250	300	160	46800	305	305	92225	310	310	96100
155	160	24800	310	165	49875	315	315	97725	320	320	102400
160	165	26400	320	170	53000	325	325	103725	330	330	108900
165	170	28050	330	175	56275	335	335	109725	340	340	11

TABLE III  
RESULTS OF TEST NO. 7

Start Test No. 7 @ 1530; Stop at 1550

RPM, disc. . . . .1300  
RPM, cylinder. . . .1200  
Speed, relative,  
f.p.s. . . . .25.5  
Ambient temp. °C . .30  
Date. . . . .15 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp. Rise °C
5	5.33	.82	2.50	2.10	.40	1	15	13
10	10.66	1.64	2.90	2.44	.46	2	15	13
15	16.00	2.46	2.95	2.63	.32	3	16	15
20	21.33	3.27	2.95	2.62	.33	4	17	19
25	26.66	4.09	3.15	2.81	.34	5	19	23
30	32.00	4.91	3.25	2.89	.36	6	20	27
35	37.33	5.73	3.35	2.97	.38	7	23	30
40	42.66	6.55	3.60	3.20	.40	8	26	39
45	48.00	7.36	3.80	3.38	.42	12	32	47
48	51.15	7.85	3.95	3.31	.64	15	34	49
48	51.15	7.85	4.00	3.36	.64	20	#44	#61

\*Approximated on basis of later timed tests.

#Temperature stabilized.



TABLE IV  
RESULTS OF TEST NO. 8

Start Test No. 8 @ 1430; Stop @ 1510

RPM, disc. . . . .1500  
RPM, cylinder. . . . .1500  
Speed, relative, f.p.s. . . . 31  
Ambient temp., °C. . . . . 27  
Date. . . . .16 May 1952

Brush Current Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	* Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp. Rise °C
5	5.33	.82	2.25	1.75	.50	13	25	27
10	10.66	1.64	2.90	2.37	.53	15	23	28
15	16.00	2.46	3.15	2.61	.54	17	23	28
20	21.33	3.27	3.30	2.72	.58	19	24	31
25	26.66	4.09	3.40	2.78	.62	21	26	33
30	32.00	4.91	3.60	2.97	.63	23	28	40
35	37.33	5.73	3.70	3.04	.66	25	31	44
40	42.66	6.55	3.80	3.12	.68	28	34	49
45	48.00	7.36	3.85	3.17	.68	30	38	55
48	51.15	7.85	4.00	3.30	.70	32	42	60
48	51.15	7.85	4.00	3.30	.70	40	#53	#73

\*Approximated on basis of later timed tests.

#Temperature stabilized.

OF THE COURT OF COMMONS

[illegible]

Brush Current Amperes	Brush Voltage Volts	Armature Current Amperes	Armature Voltage Volts	Field Current Amperes	Field Voltage Volts	Total Current Amperes	Total Voltage Volts
5	10.50	1.00	1.00	1.00	1.00	3.00	12.50
10	10.50	1.00	1.00	1.00	1.00	3.00	12.50
15	10.50	1.00	1.00	1.00	1.00	3.00	12.50
20	10.50	1.00	1.00	1.00	1.00	3.00	12.50
25	10.50	1.00	1.00	1.00	1.00	3.00	12.50
30	10.50	1.00	1.00	1.00	1.00	3.00	12.50
35	10.50	1.00	1.00	1.00	1.00	3.00	12.50
40	10.50	1.00	1.00	1.00	1.00	3.00	12.50
45	10.50	1.00	1.00	1.00	1.00	3.00	12.50
48	10.50	1.00	1.00	1.00	1.00	3.00	12.50
48	10.50	1.00	1.00	1.00	1.00	3.00	12.50



TABLE V  
RESULTS OF TEST NO. 9

Start Test No. 9 @ 1530; Stop @ 1550

RPM, disc. . . . .1800  
RPM, cylinder. . . . .1700  
Speed, relative, f.p.s. . . . 36  
Ambient temp, °C . . . . .27  
Date. . . . .16 May 1952

Brush Current, Amperes	Carbon Current Density Amp/In <sup>2</sup>	Mercury Current Density Amp/In <sup>2</sup>	Total Brush Drop Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	* Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
5	5.33	.82	2.40	1.94	.46	1	23	20
10	10.66	1.64	2.90	2.36	.54	2	24	22
15	16.00	2.46	3.05	2.51	.54	3	25	25
20	21.33	3.27	3.25	2.65	.60	4	26	28
25	26.66	4.09	3.40	2.78	.62	5	29	34
30	32.00	4.91	3.55	2.92	.63	6	33	43
35	37.33	5.73	3.65	2.97	.68	7	35	47
40	42.66	6.55	3.80	3.12	.68	9	39	51
45	48.00	7.36	4.00	3.28	.72	11	43	57
48	51.15	7.85	4.00	3.28	.72	13	47	62
48	51.15	7.85	3.85	3.15	.70	20	#55	#73

\*Approximated on basis of later timed tests.

#Temperature stabilized.

071 011 0071 0 .01 1011 1011

CONFIDENTIAL

Brush Current, Amperes	Brush Current, Volts	Brush Current, Watts	Brush Current, Amps	Brush Current, Volts	Brush Current, Watts	Brush Current, Amps	Brush Current, Volts	Brush Current, Watts
10	1.00	10.00	10	1.00	10.00	10	1.00	10.00
20	2.00	40.00	20	2.00	40.00	20	2.00	40.00
30	3.00	90.00	30	3.00	90.00	30	3.00	90.00
40	4.00	160.00	40	4.00	160.00	40	4.00	160.00
50	5.00	250.00	50	5.00	250.00	50	5.00	250.00
60	6.00	360.00	60	6.00	360.00	60	6.00	360.00
70	7.00	490.00	70	7.00	490.00	70	7.00	490.00
80	8.00	640.00	80	8.00	640.00	80	8.00	640.00
90	9.00	810.00	90	9.00	810.00	90	9.00	810.00
100	10.00	1000.00	100	10.00	1000.00	100	10.00	1000.00

• 1944 - 1945 - 1946 - 1947 - 1948 - 1949 - 1950 - 1951 - 1952 - 1953 - 1954 - 1955 - 1956 - 1957 - 1958 - 1959 - 1960 - 1961 - 1962 - 1963 - 1964 - 1965 - 1966 - 1967 - 1968 - 1969 - 1970 - 1971 - 1972 - 1973 - 1974 - 1975 - 1976 - 1977 - 1978 - 1979 - 1980 - 1981 - 1982 - 1983 - 1984 - 1985 - 1986 - 1987 - 1988 - 1989 - 1990 - 1991 - 1992 - 1993 - 1994 - 1995 - 1996 - 1997 - 1998 - 1999 - 2000 - 2001 - 2002 - 2003 - 2004 - 2005 - 2006 - 2007 - 2008 - 2009 - 2010 - 2011 - 2012 - 2013 - 2014 - 2015 - 2016 - 2017 - 2018 - 2019 - 2020 - 2021 - 2022 - 2023 - 2024 - 2025 - 2026 - 2027 - 2028 - 2029 - 2030 - 2031 - 2032 - 2033 - 2034 - 2035 - 2036 - 2037 - 2038 - 2039 - 2040 - 2041 - 2042 - 2043 - 2044 - 2045 - 2046 - 2047 - 2048 - 2049 - 2050 - 2051 - 2052 - 2053 - 2054 - 2055 - 2056 - 2057 - 2058 - 2059 - 2060 - 2061 - 2062 - 2063 - 2064 - 2065 - 2066 - 2067 - 2068 - 2069 - 2070 - 2071 - 2072 - 2073 - 2074 - 2075 - 2076 - 2077 - 2078 - 2079 - 2080 - 2081 - 2082 - 2083 - 2084 - 2085 - 2086 - 2087 - 2088 - 2089 - 2090 - 2091 - 2092 - 2093 - 2094 - 2095 - 2096 - 2097 - 2098 - 2099 - 2100 - 2101 - 2102 - 2103 - 2104 - 2105 - 2106 - 2107 - 2108 - 2109 - 2110 - 2111 - 2112 - 2113 - 2114 - 2115 - 2116 - 2117 - 2118 - 2119 - 2120 - 2121 - 2122 - 2123 - 2124 - 2125 - 2126 - 2127 - 2128 - 2129 - 2130 - 2131 - 2132 - 2133 - 2134 - 2135 - 2136 - 2137 - 2138 - 2139 - 2140 - 2141 - 2142 - 2143 - 2144 - 2145 - 2146 - 2147 - 2148 - 2149 - 2150 - 2151 - 2152 - 2153 - 2154 - 2155 - 2156 - 2157 - 2158 - 2159 - 2160 - 2161 - 2162 - 2163 - 2164 - 2165 - 2166 - 2167 - 2168 - 2169 - 2170 - 2171 - 2172 - 2173 - 2174 - 2175 - 2176 - 2177 - 2178 - 2179 - 2180 - 2181 - 2182 - 2183 - 2184 - 2185 - 2186 - 2187 - 2188 - 2189 - 2190 - 2191 - 2192 - 2193 - 2194 - 2195 - 2196 - 2197 - 2198 - 2199 - 2200 - 2201 - 2202 - 2203 - 2204 - 2205 - 2206 - 2207 - 2208 - 2209 - 2210 - 2211 - 2212 - 2213 - 2214 - 2215 - 2216 - 2217 - 2218 - 2219 - 2220 - 2221 - 2222 - 2223 - 2224 - 2225 - 2226 - 2227 - 2228 - 2229 - 2230 - 2231 - 2232 - 2233 - 2234 - 2235 - 2236 - 2237 - 2238 - 2239 - 2240 - 2241 - 2242 - 2243 - 2244 - 2245 - 2246 - 2247 - 2248 - 2249 - 2250 - 2251 - 2252 - 2253 - 2254 - 2255 - 2256 - 2257 - 2258 - 2259 - 2260 - 2261 - 2262 - 2263 - 2264 - 2265 - 2266 - 2267 - 2268 - 2269 - 2270 - 2271 - 2272 - 2273 - 2274 - 2275 - 2276 - 2277 - 2278 - 2279 - 2280 - 2281 - 2282 - 2283 - 2284 - 2285 - 2286 - 2287 - 2288 - 2289 - 2290 - 2291 - 2292 - 2293 - 2294 - 2295 - 2296 - 2297 - 2298 - 2299 - 2300 - 2301 - 2302 - 2303 - 2304 - 2305 - 2306 - 2307 - 2308 - 2309 - 2310 - 2311 - 2312 - 2313 - 2314 - 2315 - <

Table VI  
RESULTS OF TEST NO. 10

Start Test No. 10 @ 1030; stop @ 1051

RPM, disc. . . . . 2000  
RPM, cylinder. . . . . 2000  
Speed, relative, f.p.s. . . . 41  
Ambient temp., °C . . . . . 27  
Date. . . . . 19 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	* Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
5	5.33	.82	2.75	2.24	.51	1	23	20
10	10.66	1.64	3.15	2.62	.53	2	25	23
15	16.00	2.46	3.35	2.77	.58	3	26	26
20	21.33	3.27	3.45	2.87	.58	4	27	30
25	26.66	4.09	3.60	2.98	.62	5	29	35
30	32.00	4.91	3.65	3.01	.64	7	33	42
35	37.33	5.73	3.70	3.06	.64	9	36	46
40	42.66	6.55	3.90	3.20	.70	11	40	50
45	48.00	7.36	4.00	3.27	.73	13	43	56
48	51.15	7.85	4.00	3.27	.73	15	47	63
48	51.15	7.85	4.00	3.27	.73	21	#57	#73

\*Approximated on basis of later timed tests.

#Temperature stabilized.

# Table 1 OF THE ...

Start Test No. 1 20:00

... ..  
... ..  
... ..  
... ..  
... ..

British Current Amperes	Carbon Current Amperes	Carbon Current Volts	Carbon Current Watts	Carbon Current Efficiency	Carbon Current Resistance	Carbon Current Temperature	Carbon Current Remarks
5	10.35	1.04	10.76	1.04	1.04	1.04	1.04
10	10.35	1.04	10.76	1.04	1.04	1.04	1.04
15	10.35	1.04	10.76	1.04	1.04	1.04	1.04
20	10.35	1.04	10.76	1.04	1.04	1.04	1.04
25	10.35	1.04	10.76	1.04	1.04	1.04	1.04
30	10.35	1.04	10.76	1.04	1.04	1.04	1.04
35	10.35	1.04	10.76	1.04	1.04	1.04	1.04
40	10.35	1.04	10.76	1.04	1.04	1.04	1.04
45	10.35	1.04	10.76	1.04	1.04	1.04	1.04
48	10.35	1.04	10.76	1.04	1.04	1.04	1.04
48	10.35	1.04	10.76	1.04	1.04	1.04	1.04

\*Approximate ...  
... ..

TABLE VII

## RESULTS OF TEST NO. 11

Start \*Test No. 11 @ 1117; Stop @ 1142

RPM, disc. . . . . 2250  
 RPM, cylinder. . . . . 2250  
 Speed, relative, f.p.s . . . . 46.5  
 Ambient temp., °C . . . . . 27  
 Date . . . . . 19 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
5	5.33	.82	2.80	2.22	.58	1	27	22
10	10.66	1.64	3.20	2.60	.60	4	28	24
15	16.00	2.46	3.30	2.68	.62	5	29	26
20	21.33	3.27	3.35	2.72	.63	6	29	27
25	26.66	4.09	3.50	2.85	.65	8	31	32
30	32.00	4.91	3.65	2.97	.68	9	32	37
35	37.33	5.73	3.80	3.11	.69	11	33	42
40	42.66	6.55	3.80	3.09	.71	12	35	47
45	48.00	7.36	4.00	3.28	.72	13	37	52
48	51.15	7.85	4.00	3.27	.73	15	40	57
48	51.15	7.85	4.05	3.35	.70	25	#44	#69

\*For Test No. 11 and subsequent tests, an 18" fan was directed on the cylinder from a distance of about 12". Estimate blast at 1" to 2" of water.

#Temperature stabilized.

STANDARD TEST FOR THE DETERMINATION OF THE

RELATIONSHIP BETWEEN THE TEMPERATURE OF THE  
 SOLUTION AND THE RATE OF REACTION  
 IN THE PRESENCE OF A CATALYST

Current, Amperes	Temperature, °C.	Rate of Reaction, %/min.	Concentration, M.	Time, min.	Volume, ml.	Pressure, mm.
2	20	0.03	0.01	1	10	760
10	20	0.06	0.01	1	10	760
15	20	0.09	0.01	1	10	760
20	20	0.12	0.01	1	10	760
25	20	0.15	0.01	1	10	760
30	20	0.18	0.01	1	10	760
35	20	0.21	0.01	1	10	760
40	20	0.24	0.01	1	10	760
45	20	0.27	0.01	1	10	760
48	20	0.30	0.01	1	10	760
50	20	0.32	0.01	1	10	760
52	20	0.34	0.01	1	10	760
54	20	0.36	0.01	1	10	760
56	20	0.38	0.01	1	10	760
58	20	0.40	0.01	1	10	760
60	20	0.42	0.01	1	10	760
62	20	0.44	0.01	1	10	760
64	20	0.46	0.01	1	10	760
66	20	0.48	0.01	1	10	760
68	20	0.50	0.01	1	10	760
70	20	0.52	0.01	1	10	760
72	20	0.54	0.01	1	10	760
74	20	0.56	0.01	1	10	760
76	20	0.58	0.01	1	10	760
78	20	0.60	0.01	1	10	760
80	20	0.62	0.01	1	10	760
82	20	0.64	0.01	1	10	760
84	20	0.66	0.01	1	10	760
86	20	0.68	0.01	1	10	760
88	20	0.70	0.01	1	10	760
90	20	0.72	0.01	1	10	760
92	20	0.74	0.01	1	10	760
94	20	0.76	0.01	1	10	760
96	20	0.78	0.01	1	10	760
98	20	0.80	0.01	1	10	760
100	20	0.82	0.01	1	10	760

NOTE: The rate of reaction was determined by measuring the volume of gas evolved in a given time. The temperature of the solution was maintained constant by using a water bath. The concentration of the solution was 0.01 M. The pressure was 760 mm. Hg.

TABLE VIII

## RESULTS OF TEST NO. 12

Start Test No. 12 @ 1155; Stop @ 1218

RPM, disc. . . . . 2500  
 RPM, cylinder. . . . . 2500  
 Speed, relative, f.p.s . . . . . 51  
 Ambient temp., °C . . . . . 27  
 Date. . . . . 19 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
5	5.33	.82	2.75	2.16	.59	1	33	24
10	10.66	1.64	3.00	2.40	.60	2	34	24
15	16.00	2.46	3.10	2.48	.62	3	35	26
20	21.33	3.27	3.15	2.52	.63	5	36	29
25	26.66	4.09	3.20	2.55	.65	7	38	31
30	32.00	4.91	3.30	2.62	.68	9	39	36
35	37.33	5.73	3.75	3.05	.70	10	40	40
40	42.66	6.55	3.85	3.15	.70	12	42	46
45	48.00	7.36	4.00	3.28	.72	14	43	53
48	51.15	7.85	4.10	3.36	.74	15	45	58
48	51.15	7.85	4.15	3.47	.68	23	#49	#72

#Temperature stabilized.

Start Test No. 12 at 11:55 A.M.

Water . . . . . 1.00  
Residual Water . . . . . 0.00  
Steam, wet . . . . . 0.00  
Dry, cylinder . . . . . 0.00  
Loss, disc . . . . . 0.00

Brush Current, Amperes	Brush Voltage, Volts	Armature Current, Amperes	Armature Voltage, Volts	Field Current, Amperes	Field Voltage, Volts	Speed, R.P.M.	Time, Sec.
5	1.33	1.33	1.33	1.33	1.33	1.33	1.33
10	1.33	1.33	1.33	1.33	1.33	1.33	1.33
15	1.33	1.33	1.33	1.33	1.33	1.33	1.33
20	1.33	1.33	1.33	1.33	1.33	1.33	1.33
25	1.33	1.33	1.33	1.33	1.33	1.33	1.33
30	1.33	1.33	1.33	1.33	1.33	1.33	1.33
35	1.33	1.33	1.33	1.33	1.33	1.33	1.33
40	1.33	1.33	1.33	1.33	1.33	1.33	1.33
45	1.33	1.33	1.33	1.33	1.33	1.33	1.33
48	1.33	1.33	1.33	1.33	1.33	1.33	1.33

Temperature of water . . . . .



TABLE IX  
RESULTS OF TEST NO. 13

Start Test No. 13 @ 1425; stop @ 1447

RPM, disc. . . . . 2750  
RPM, cylinder. . . . . 2750  
Speed, relative, f.p.s . . . 57  
Ambient temp., °C. . . . . 27  
Date. . . . . 19 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
5	5.33	.82	2.30	1.75	.55	1	36	20
10	10.66	1.64	2.55	1.95	.60	2	36	22
15	16.00	2.46	2.90	2.26	.64	4	36	26
20	21.33	3.27	3.20	2.52	.68	5	36	28
25	26.66	4.09	3.40	2.70	.70	6	38	31
30	32.00	4.91	3.45	2.75	.70	9	41	38
35	37.33	5.73	3.65	2.93	.72	10	42	41
40	42.66	6.55	3.70	2.97	.73	12	43	45
45	48.00	7.36	3.85	3.10	.75	13	45	51
48	51.15	7.85	3.90	3.13	.77	15	47	56
48	51.15	7.85	4.15	3.39	.76	22	#52	#68

#Temperature stabilized.

Start Test No. 1450 and 1451

Notes: 1. The data were obtained from the test results of the 1950 test series. 2. The data were obtained from the test results of the 1950 test series. 3. The data were obtained from the test results of the 1950 test series.

Amperes	Brush Current, Amperes	Carbon Current, Amperes	Carbon Current, Volts	Carbon Current, Volts	Carbon Current, Volts	Carbon Current, Volts	Carbon Current, Volts	Carbon Current, Volts	Carbon Current, Volts
5	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
10	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
15	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
20	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
25	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
30	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
35	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
40	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
45	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
48	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50

Notes: 1. The data were obtained from the test results of the 1950 test series. 2. The data were obtained from the test results of the 1950 test series. 3. The data were obtained from the test results of the 1950 test series.

TABLE X

## RESULTS OF TEST NO. 14

Start Test No. 14 @ 1524; Stop @ 1551

RPM, disc. . . . . 3000  
 RPM, cylinder. . . . . 3000  
 Speed, relative, f.p.s . . . . 62  
 Ambient temp., °C. . . . . 30  
 Date. . . . . 19 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
5	5.33	.82	2.80	2.23	.57	1	48	15
5	5.33	.82	2.90	2.27	.63	9	45	20
10	10.66	1.64	3.15	2.52	.65	10	45	22
15	16.00	2.46	3.25	2.60	.68	12	46	23
20	21.33	3.27	3.50	2.82	.70	14	47	25
25	26.66	4.09	3.80	3.10	.72	16	48	33
30	32.00	4.91	3.90	3.18	.73	17	49	37
35	37.33	5.73	4.00	3.27	.74	18	50	40
40	42.66	6.55	4.20	3.46	.77	20	51	45
45	48.00	7.36	4.40	3.63	.78	21	53	50
48	51.15	7.85	4.50	3.72	.77	22	55	57
48	51.15	7.85	4.45	3.68		27	#58	#66

#Temperature stabilized.

CONFIDENTIAL

0002 . . . . . south . . .  
0003 . . . . . involved . . .  
0004 . . . . . evidence . . .  
0005 . . . . . signed the form . . .  
0006 . . . . .

Year	Month	Day	Time	Location	Weather	Temperature	Humidity	Wind	Pressure	Clouds	Visibility	Notes
1917	Jan	1	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	2	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	3	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	4	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	5	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	6	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	7	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	8	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	9	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	10	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	11	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	12	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	13	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	14	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	15	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	16	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	17	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	18	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	19	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	20	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	21	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	22	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	23	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	24	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	25	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	26	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	27	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	28	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	29	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	30	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	
1917	Jan	31	10:00	San Francisco	Clear	45.0	65.0	10.0	30.0	0.0	10.0	

• 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 2222 2223 2224 2225 2226 2227 2228 2229 2230 2231 2232 2233 2234 2235 2236 2237 2238 2239 2240 2241 2242 2243 2244 2245 2246 2247 2248 2249 2250 2251 2252 2253 2254 2255 2256 2257 2258 2259 2260 2261 2262 2263 2264 2265 2266 2267 2268 2269 2270 2271 2272 2273 2274 2275 2276 2277 2278 2279 2280 2281 2282 2283 2284 2285 2286 2287 2288 2289 2290 2291 2292 2293 2294 2295 2296 2297 2298 2299 2300 2301 2302 2303 2304 2305 2306 2307 2308 2309 2310 2311 2312 2313 2314 2315 2316 2317 2318 2319 2320 2321 2322 2323 2324 2325 2326 2327 2328 2329 2330 2331 2332 2333 2334 2335 2336 2337 2338 2339 2340 2341 2342 2343 2344 2345 2346 2347 2348 2349 2350 2351 2352 2353 2354 2355 2356 2357 2358 2359 2360 2361 2362 2363 2364 2365 2366 2367 2368 2369 2370 2371 2372 2373 2374 2375 2376 2377 2378 2379 2380 2381 2382 2383 2384 2385 2386 2387 2388 2389 2390 2391 2392 2393 2394 2395 2396 2397 2398

TABLE XI

## RESULTS OF TESTS NO. 15 &amp; 16

Start Test No. 15 @ 1600; Stop @ 1611

RPM, disc. . . . . 3250  
 RPM, cylinder. . . . . 3250  
 Speed, relative, f.p.s. . . . 67  
 Ambient temp., °C. . . . . 30  
 Date. . . . . 19 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
48	51.15	7.85	4.30	3.55	.75	3	#64	54
48	51.15	7.85	4.50	3.75	.75	9	#67	64
48	51.15	7.85	4.50	3.75	.75	11	#70	66

Start Test No. 16 @ 1020; Stop @ 1032

RPM, disc. . . . . 3500  
 rpm, cylinder. . . . . 3500  
 Speed, relative, f.p.s. . . . 72  
 Ambient temp., °C. . . . . 25  
 Date. . . . . 21 May 1952

48	51.15	7.85	4.30	3.55	.75	6	57	61
48	51.15	7.85	4.30	3.55	.75	7	60	65
48	51.15	7.85	4.45	3.69	.76	8	62	69
48	51.15	7.85	4.40	3.63	.77	9	64	70
48	51.15	7.85	4.25	3.47	.78	10	66	71
48	51.15	7.85	4.30	3.52	.78	11	67	72
48	51.15	7.85	4.40	3.62	.78	12	69	73

#Suspect this excessive rise due to binding seal.

State Test No. 15 1000 - top 1 1 15

1000 . . . . .  
 1000 . . . . .  
 1000 . . . . .  
 1000 . . . . .  
 1000 . . . . .

Brush Current, Amperes	Carbon Current, Amperes	Brush Current, Amperes	Carbon Current, Amperes	Brush Current, Amperes	Carbon Current, Amperes	Brush Current, Amperes	Carbon Current, Amperes
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48

State Test No. 15 1000 - top 1 1 15

1000 . . . . .  
 1000 . . . . .  
 1000 . . . . .  
 1000 . . . . .  
 1000 . . . . .

48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48
48	48	48	48	48	48	48	48

## TABLE XII

## RESULTS OF TESTS NO. 17, 18 &amp; 19

Brush Current, Amperes	Carbon Current Density Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
------------------------------	---	---	----------------------------------	-----------------------------------	------------------------------------	-----------------------------	----------------------------	--------------------------------

Test No. 17

RPM, disc. . . . . 3750  
 RPM, cylinder. . . . . 3750  
 Speed, relative, f.p.s. . 77.5  
 Ambient temp., °C. . . . 25  
 Date. . . . . 21 May 1952

48	51.15	7.85	4.40	3.65	.75	*10	#57	43
1	1.07	.16	--	--	.50	1	---	--

Test No. 18<sup>1</sup>

RPM, disc. . . . . 1500  
 RPM, cylinder. . . . . 1500  
 Speed, relative, f.p.s. . 31  
 Ambient temp., °C. . . . 25  
 Date. . . . . 21 May 1952

48	51.15	7.85	4.00	3.50	.50	*10	#47	25
----	-------	------	------	------	-----	-----	-----	----

<sup>2</sup>Test No. 19

RPM, disc. . . . . 4000  
 RPM, cylinder. . . . . 4000  
 Speed, relative, f.p.s. . 83  
 Ambient temp., °C. . . . 30  
 Date. . . . . 23 May 1952

48	51.15	7.85	5.00	4.22	.78	5	#70	60
1	1.07	.16	----	----	.50	1	---	--

<sup>1</sup>Continuation Test No. 17 wherein RPM reduced abruptly.

<sup>2</sup>Reversed polarity; made disc (+); also reduced carbon brush pressure to minimum.

\*Estimated

#Due to binding seal.

OF THE . . .

VI. 01 2292

9	77	07.	70.	07.	78.7	77.77	84
---	---	1	---	---	81.	70.7	1

BT. On test

84

of .01 days

	7	10.	69.	60.	81.	71.	84
--	--	--	--	--	--	--	--

Continuation of Form No. 10-67 (Rev. 1-18-67)

Reversed Political Action Committee (RAPAC) - Program designed to identify

\*Not certified\*

\* From 1st into 2nd



TABLE XIII

## RESULTS OF TEST NO. 20

Start Test No. 20 @ 1120; stop @ 1230

RPM, disc. . . . . 4000  
 RPM, cylinder. . . . . 4000  
 Speed, relative, f.p.s. . . 83  
 Ambient temp., °C. . . . . 25  
 Date. . . . . 26 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Brush Drop, Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
48	51.15	13.20	5.60	5.00	.60	14	57	63
			5.65	5.03	.62	15	59	63
			5.65	5.03	.62	16	60	62
			5.60	4.98	.62	18	60	65
			5.60	4.92	.68	21	60	66
			5.60	4.88	.72	24	60	67
			5.65	4.95	.70	26	60	68
			5.50	4.78	.72	29	60	70
			5.40	4.80	.60	30	59	70
			5.40	4.80	.60	31	59	70
			5.60	4.92	.68	33	57	70
			5.40	4.76	.64	39	58	72
			5.25	4.61	.64	41	57	71
			5.20	4.42	.78	43	57	71
			5.40	4.80	.60	45	57	71
			5.50	4.86	.64	46	57	71
48 5	51.15 5.33	13.20 1.38	2.50	2.12	.38	47	53	67
			3.20	2.74	.46	49	47	52
			3.20	2.70	.50	51	42	40
			3.40	2.95	.45	53	39	33
			3.40	2.97	.43	56	37	29
			3.60	3.10	.50	58	37	27
			3.50	3.00	.50	60	38	26
5 0 0	5.33 0 0	1.38 0 0	3.45	2.95	.50	63	38	26
			0	0	0	66	39	24
			0	0	0	70	38	24



### RESULT OF TEST NO. 21

[illegible]

Brush Current Amperes,	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density Amp/In <sup>2</sup>	Total Brush Drop Volts	Carbon Brush Drop, Volts	Mercury Brush Drop, Volts	Elapsed Time, Minutes	Disc Temp. Rise °C	Cylinder Temp. Rise °C
0	0	0	0	0	0	5	42	15
						8	49	16
						10	38	16
						11	49	16
0	0	0	0	0	0	12	49	16
5	5.33	3.45	4.30	3.82	.48	13	49	19
5	5.33	3.45	4.40	3.92	.48	16	50	19
25	26.66	17.20	5.25	4.59	.66	17	52	25
			5.25	4.63	.62	19	54	32
			5.35	4.73	.62	21	55	37
			5.40	4.78	.62	23	54	38
			5.40	4.79	.61	25	54	40
			5.50	4.86	.64	28	54	41
			5.50	4.82	.68	30	54	42
			5.50	4.80	.70	33	53	43
			5.50	4.80	.70	33	53	43
25	26.66	17.20	5.50	4.83	.67	35	52	43
48	51.15	33.10	6.25	5.52	.73	36	55	47
48	51.15	33.10	6.05	5.32	.73	37	58	53
48	51.15	33.10	6.05	5.34	.71	38	59	59
48	51.15	33.10	6.00	5.30	.70	39	61	61
48	51.15	33.10	5.80	5.12	.68	40	62	66
48	51.15	33.10	5.85	5.15	.70	42	62	68
48	51.15	33.10	5.80	5.13	.67	43	62	69
48	51.15	33.10	5.80	5.20	.60	45	62	71
48	51.15	33.10	6.00	5.42	.58	47	62	72
48	51.15	33.10	6.00	5.40	.60	50	63	73
25	26.66	17.20	5.30	4.70	.60	51	61	70
25	26.66	17.20	5.50	4.87	.63	52	58	69
25	26.66	17.20	5.60	5.05	.55	53	58	60
5	5.33	3.45	3.95	3.43	.52	54	55	53
5	5.33	3.45	4.30	3.80	.50	56	53	45
5	5.33	3.45	4.65	4.00	.65	57	53	40
0	0	0	0	0	0	58	52	35
0	0	0	0	0	0	60	52	33



TABLE XV  
RESULTS OF TESTS NO. <sup>22</sup>23, 23

Started Test No. 22 @ 1433; stop @ 1453

RPM, disc. . . . . 3000  
RPM, cylinder. . . . . 3000  
Speed, relative, f.p.s. . . 62  
Ambient temp., °C. . . . . 25  
Date. . . . . 26 May 1952

Brush Current, Amperes	Carbon Current Density, Amp/In <sup>2</sup>	Mercury Current Density, Amp/In <sup>2</sup>	Total Drop, Volts	Brush Drop Volts	Carbon Brush Drop Volts	Mercury Brush Drop Volts	Elapsed Time Minutes	Disc Temp Rise °C	Cylinder Temp Rise °C
		①							
48	51.15	33.10	5.60	5.25	.35	1	37	30	
48	51.15	33.10	4.50	4.18	.32	3	37	30	
48	51.15	33.10	4.60	4.20	.40	10	40	63	
48	51.15	33.10	5.50	5.12	.38	13	43	67	
25	26.66	17.20	----	----	.26	15	40	65	
25	26.66	17.20	4.50	4.15	.35	19	40	50	
5	5.33	3.45	2.70	2.65	#.05	20	--	--	

① Density probably much greater, as open-ckt developed shortly after Test 22.

Started Test No. 23 @ 1542; Stop @ 1606  
Date, RPM, Ambient Same as Test No. 22

48	51.15	13.20	5.40	4.80	.60	1	25	48
			5.40	4.70	.70	4	33	53
			5.70	5.00	.70	6	35	58
			5.50	4.80	.70	8	37	61
			5.40	4.70	.70	10	39	62
			5.40	4.70	.70	12	40	63
			5.50	4.80	.70	14	40	63
48	51.15	13.20	5.50	4.80	.70	14	40	63
48	51.15	13.20	----	----	---	18	40	*--
5	5.33	1.38	3.00	2.40	.60	20	35	--
5	5.33	1.38	3.10	2.55	.55	22	28	--
5	5.33	1.38	3.40	2.85	.55	24	23	--

#This low reading no mistake; current was varied 0 to 50 and reading repeated.

\*At this point, cylinder thermometer vibrated out of shaft and was bent.



# SUMMARY OF TESTS No. 20, 21, 22 & 23

TABLE XVI

Brush Current Amps.	Hg Current Density Amp/In <sup>2</sup>	Rel. Spd. F.P.S.	Hg Volt Drop	Test Number
48	13.2	83	.66	20
5	1.38	83	.48	20
5	3.45	107	.52	21
25	17.2	107	.63	21
48	33.1	107	.67	21
48	33.1	62	.36	22
25	17.2	62	.30	22
5	3.45	62	.05	22
48	13.2	62	.69	23
5	1.38	62	.57	23

NOTE: Column 4 is an average over a "steady-state" period.

SECRET

100

Amperes.	Current Density amp./sq. in.	Volts.	Watts.	Heat in Btu per hour.
48	17.2	1.9	1.0	90
5	1.38	63	1.0	90
5	1.42	107	1.0	110
25	17.2	107	1.3	110
48	17.1	107	1.34	110
48	17.1	1	1.36	80
25	17.2	62	1.50	80
5	1.42	62	1.52	80
48	17.0	62	1.54	63
5	1.38	62	1.57	63



TABLE XVII

## TEMPERATURE RISE SUMMARY OF ALL TESTS

Brush Curr. Amps.	Rel. Spd. F.P.S.	Aver. Temp. Rdgs. °C	Test No.	Brush Curr. Amps.	Rel. Spd. F.P.S.	Aver. Temp. Rdgs. °C	Test No.	Brush Curr. Amps.	Rel. Spd. FPS	Aver. Temp. Rdgs. °C	Test No.
5	20	15	6	5	46.5	25	11	5	83	32	20
25	20	21	6	25		32		48		64	
48	20	54	6	48		56		0		31	
5	25.5	14	7	5	51	28	12	0	107	32	21
25	25.5	21	7	25		35		5		34	
48	25.5	53	7	48		60		25		48	
								48		68	
5	31	26	8	5	57	28	13				
25		30	8	25		35		48	62	52	23
48		63	8	48		60					
5	36	21	9	5	62	32	14				
25		32		25		40					
48		64		48		62					
5	41	22	10	48	67	68	15				
25		32									
48		65		48	72	71	16				

[illegible]

TABLE XVIII  
SOME PHYSICAL PROPERTIES  
OF  
MERCURY, IRON, COPPER

	<u>Hg.</u>	<u>Fe</u>	<u>Cu</u>
Atomic Weight	200.61	55.84	63.57
Density, gm. per cc.	13.546	7.87	8.89
Melting Point, °C	-38.87	1535	1083
Latent Heat of Fusion, g-Cal per g.	2.776	65	49.3
Boiling Point, °C	356.9	3200	2300
Latent Heat of Vaporization, g-cal per g.	71	1110	1756
Specific heat, Btu per lb.	.0333	.1075	.0928
Thermal Coeff. of Linear Expansion, x 10 <sup>4</sup> per °C	#	.119	.162
Thermal Cond., g-cal/sec/ cm <sup>2</sup> /°C/cm	.0148	.18	.918
Electrical Resistivity, ohm cm cube	95.783	9.8	1.724
Temp Coeff of Resistivity	.00089	.0065	.00393

$$\# \frac{1}{v} \frac{dv}{dt} = 182 \times 10^{-6} @ 20^{\circ}\text{C}$$







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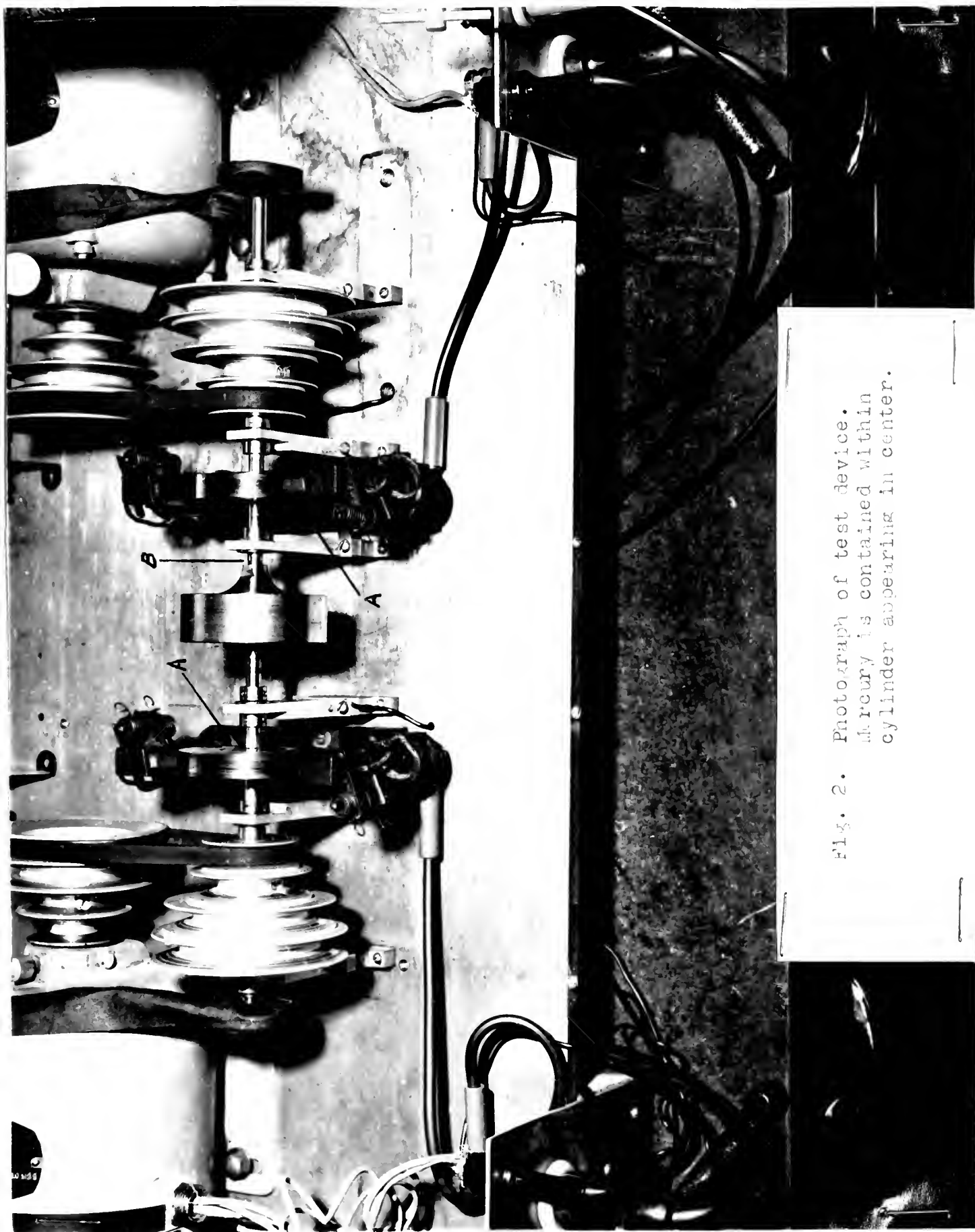


Fig. 2. Photograph of test device.  
Mercury is contained within  
cylinder appearing in center.





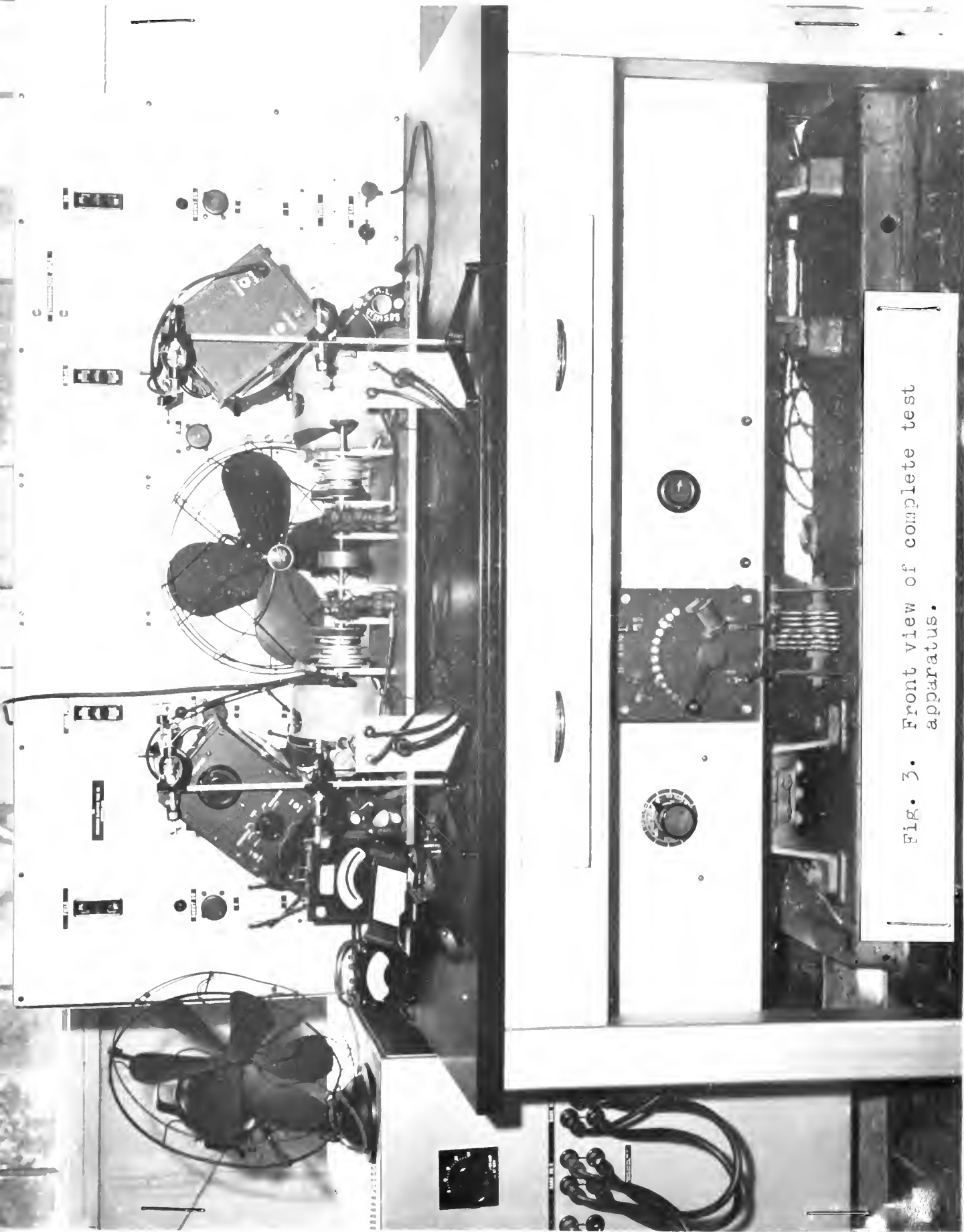
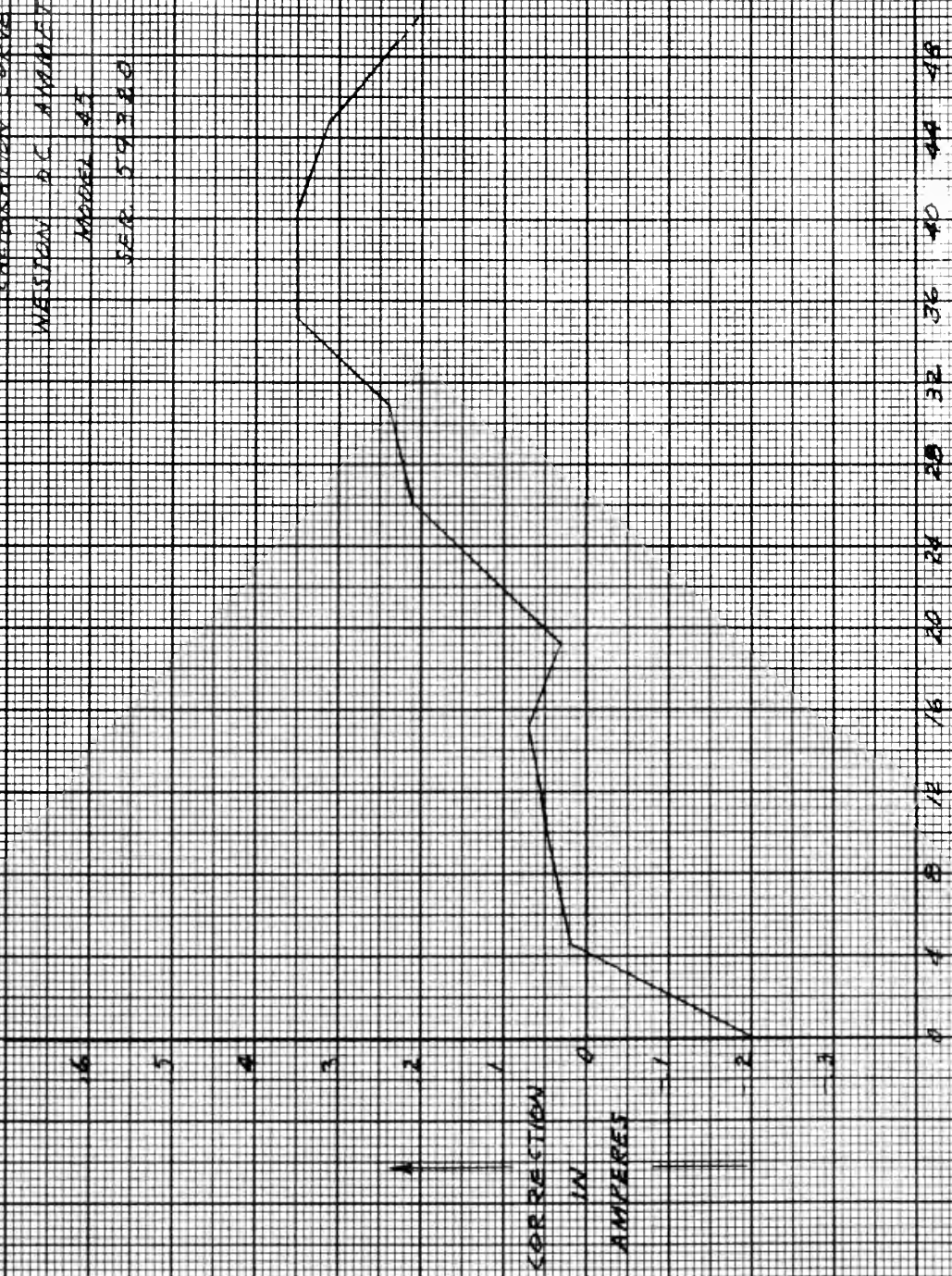


Fig. 3. Front view of complete test apparatus.



FIG. 4

CALIBRATION CURVE  
WESTON DC AMMETER  
MODEL 45  
SER 59220



SCALE INDICATION, AMPERES

87 FEB 1955

1

1

1

1

CORRECTION

IN

VOLTS

FIG. 5

CALIBRATION CURVE  
GENERAL ELECTRIC DC VOLTMETER

SER. 1112214

SCALE INDICATION, VOLTS

0214051P54

30

28

26

24

22

20

18

16

14

12

10

8

6

4

2

0

0

0

0

0

0

0

0

0

11

11

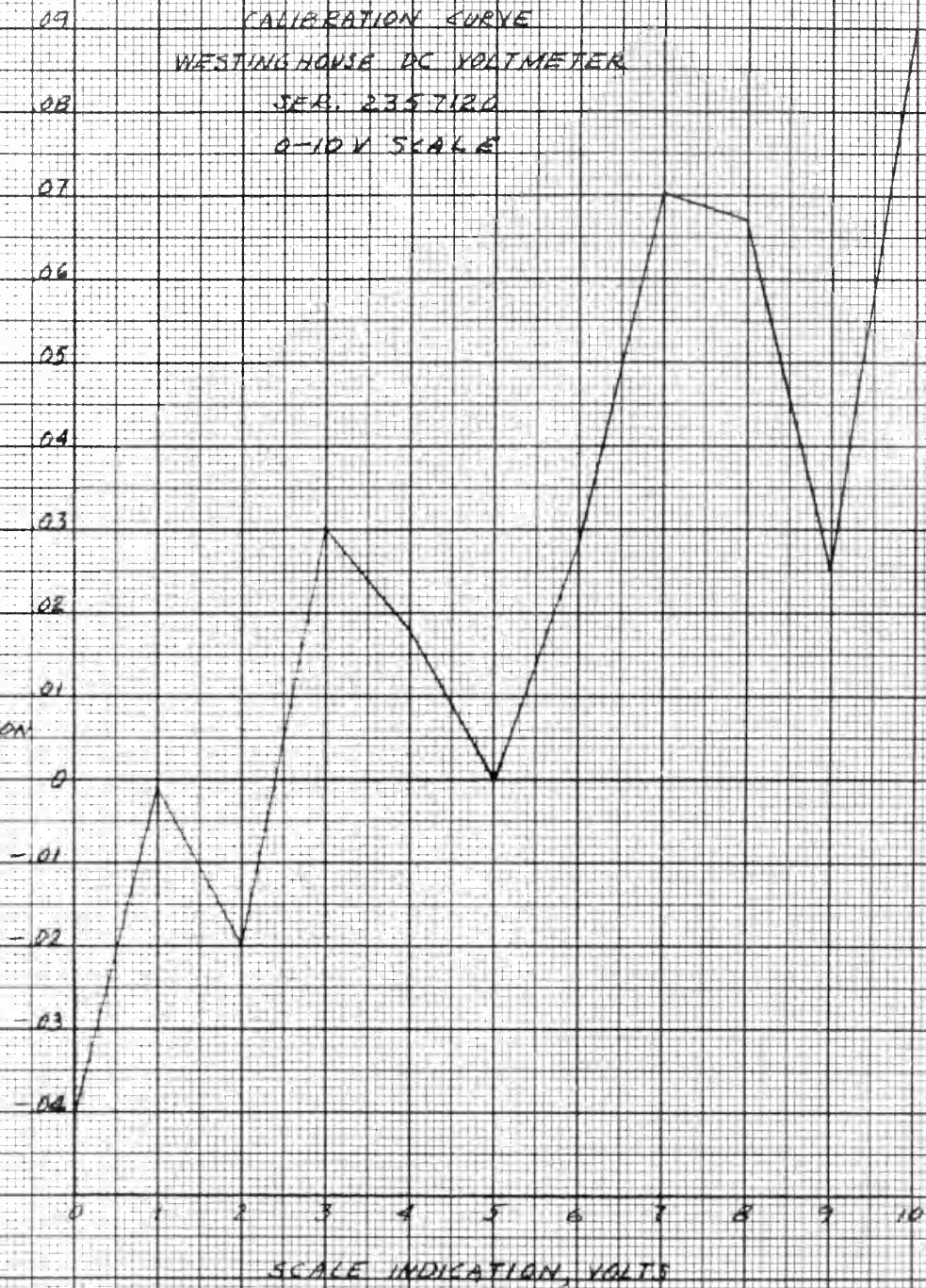
11

11



FIG. 6  
 CALIBRATION CURVE  
 WESTINGHOUSE DC VOLT METER  
 SER. 2357120  
 0-10V SCALE

CORRECTION  
 IN  
 VOLTS



22 May 1952

1

1





Fig. 7. Left side view of apparatus.



Item  
445

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—

—



Fig. 8. Right side view of apparatus.



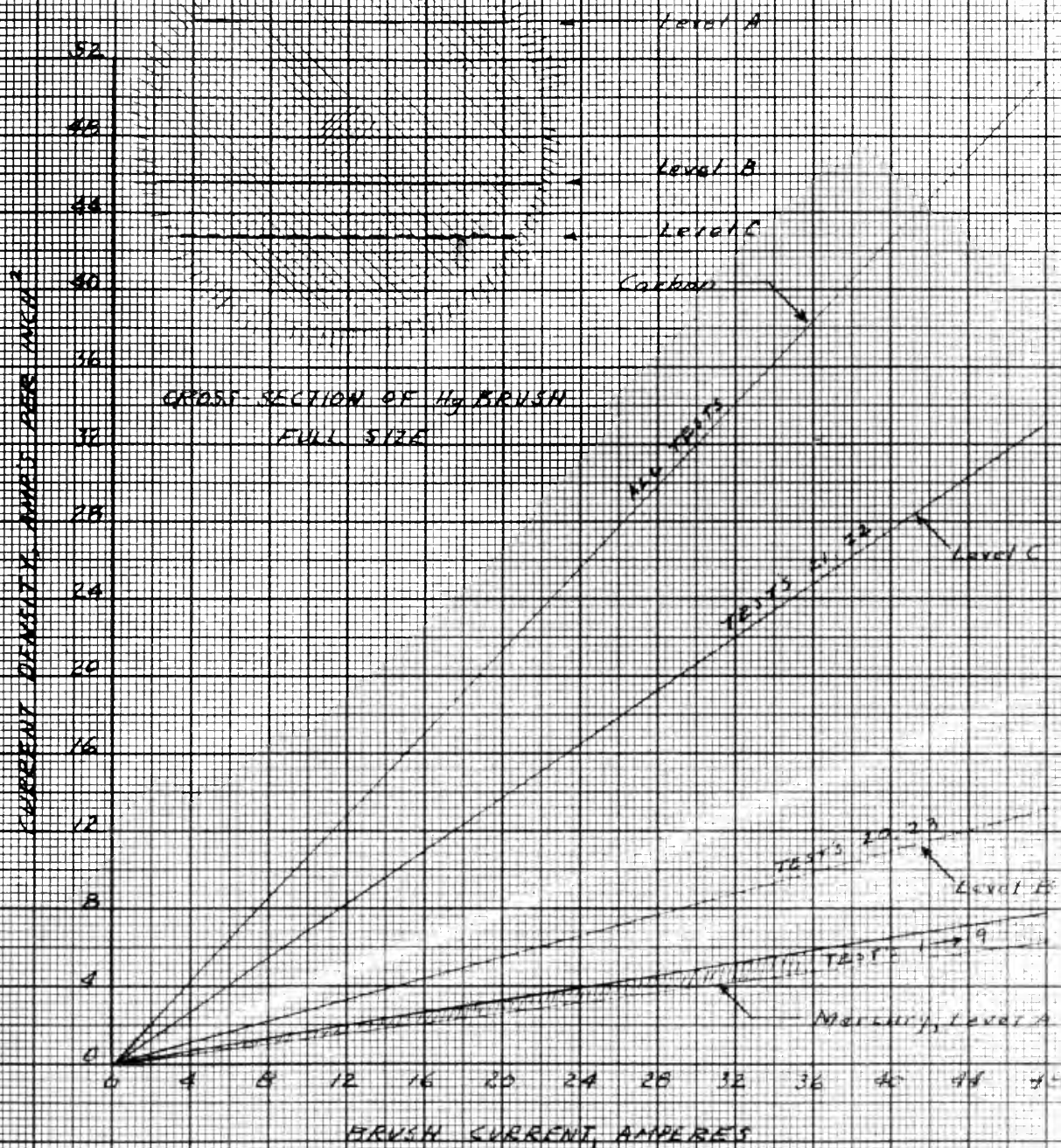


FIG. 9. CURVE OF CURRENT DENSITIES

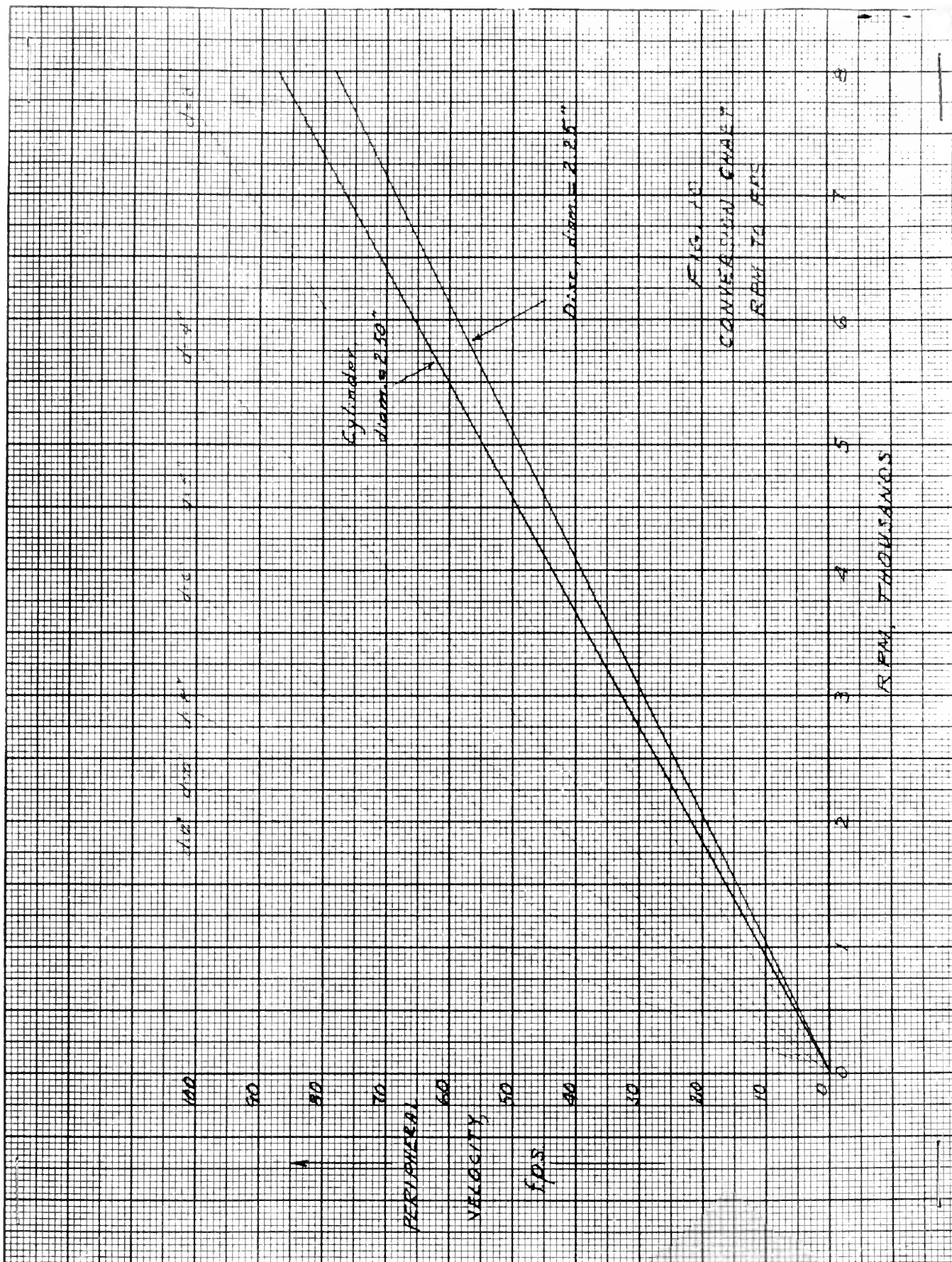
11

12

11

12









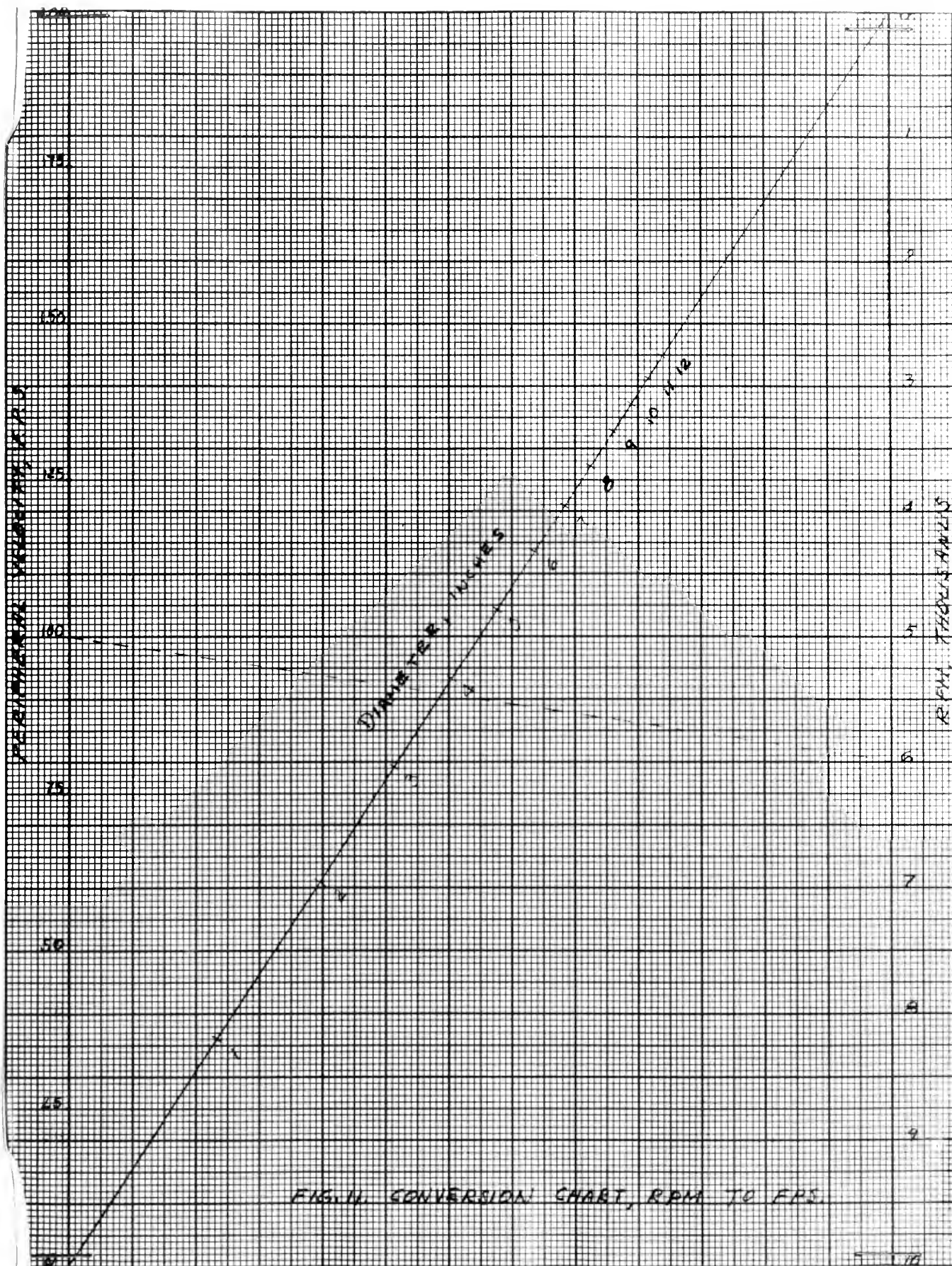


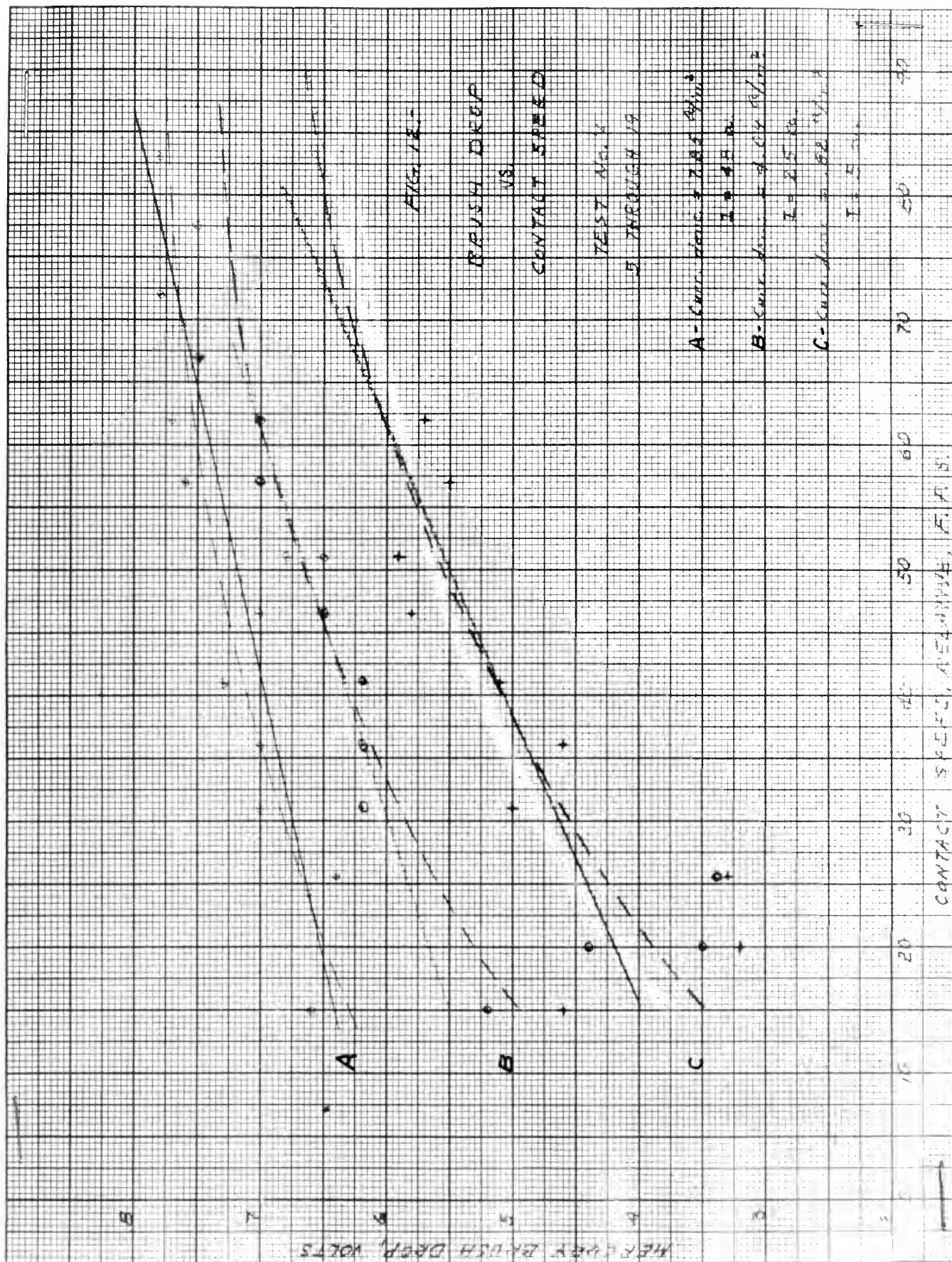
FIG. 11. CONVERSION CHART, RPM TO FPS

1

1

1

1



—

1

1

1



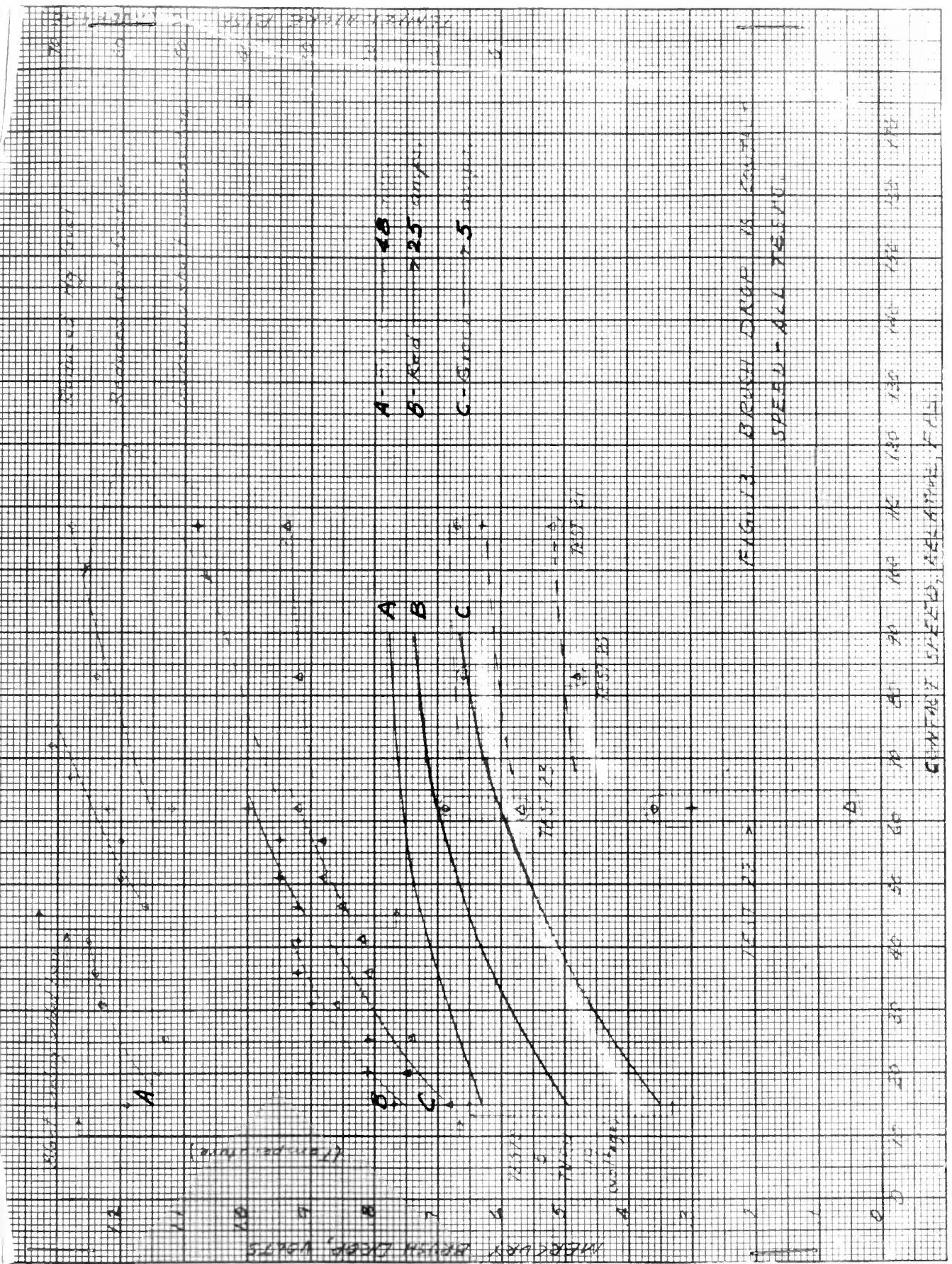


FIGURE 13. BRUSH DROP VS. SPEED  
SPEED - ALL FEET

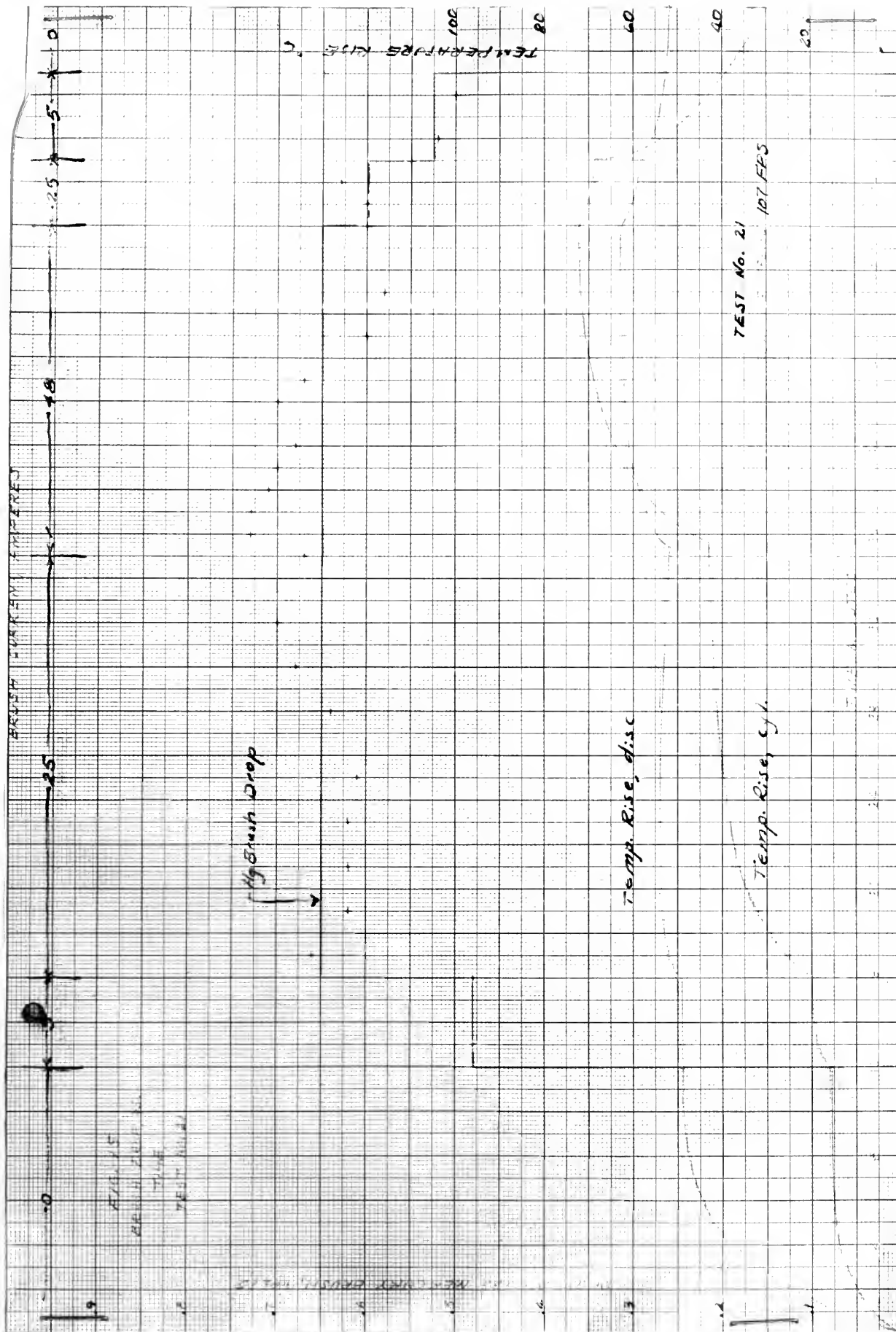
CHART 7: SPEED, RELATIVE FALL

















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APPENDIX A  
LABORATORY LOG

---

$\frac{1}{\sqrt{2}} \begin{pmatrix} 1 & i \\ -1 & i \end{pmatrix}$

22 APRIL 1952

Finally got down to work on thesis project at about 1415 p.m. Disassembled, cleaned and oiled. Fitted the carbon brushes to the brass slip rings. Required the help of Joe Octavek to open the cylinder in order that preservative oil could be cleaned out. Noted DC motors are shunt wound. Will have to exercise care that field doesn't open inadvertently.

For power will have to start up synchronous motor, DC generator set.

23 APRIL 1952

Cleaned oil out of conducting cylinder. Re-aligned and tightened entire mechanism. Mounted 2 armature slide-wire rheostats and 2 field slide-wire rheostats. Next plan to connect and test DC motors; be sure to uncouple v-belts. In testing for grounds, noted one v-belt shows less than infinite (500k) resistance. Re-check on 7 May showed infinite R both belts.

24 April 1952

Installed terminal lugs, connected motors. Started up AC-DC set and tested motors. Both run satisfactorily. Next plan to test rotary brush assembly for alignment and heat (temp.) rise.

25 APRIL 1952

Started the mechanism on slowest possible speed (motors on smallest pulleys) and noted temperature rises. Cylinder end stabilized at about 400-500 C, whereas disc end tended





to overheat (600-800°C). After a run-in of 30-40 minutes, disc end steadied at about 600°C. Next set motors on largest pulleys. Without extreme care in speed control, it was possible to rapidly and easily overheat the disc end. Trouble was at mercury seal, a pressed paper sleeve (journal) bearing on the disc shaft (and rotating with the cylinder). Temperature of disc end went as high as 1600°C; cylinder end steady at about 500°C. Permitted speeds such that disc end ran at about 1000-1200°C for 30-40 minutes. Noted small amount bearing grease on paper seal <sup>was</sup> of great help. Secured device, packed small quantity grease about paper seal in hope sufficient absorption would take place to permit cooler running. Necessary that device run cool in order to avoid danger of flashing mercury into vapor. To this extent, must remember to provide a ventilating blower once mercury is placed in cylinder.

30 APRIL 1952

Started device. Temperatures both ends steady at about 450-500°C., even at relative speed of 12,000 rpm. Connected and adjusted two strobotacs. Connected adjustable load resistor bank (1-72 amps) to provide current control for rotating brush. Connected ammeter and voltmeter to record current through brush and drops across carbon and Hg together and across Hg alone.

To provide for maximum control of speed and current, started up another M-G set. One set provided voltage for driving motors; other set providing voltage for load

[illegible][illegible]

resistor bank. In this way, have two speed controls: (1) field rheostat on DC generator; (2) armature and field rheostats in DC motors. Also then have two current controls: (1) field rheostat on second DC generator; (2) rotary switch on load bank (parallel connected).

Load bank is good for 72 amps. (Go to 48 amps.)

Started up both M-G sets; brought motors up to speed (about 4,000 each rpm); shorted out rotating brush (since as yet no mercury in it); and put about 6 amps through carbon brush assembly. Noted voltmeters as connected to read from pedestal-to-pedestal would give no readings. Investigation showed grease on bearings sufficient to act as insulator. In probing with ohmmeter, noted resistance of rotating brush had dropped from about 500  $k\Omega$  (prior to greasing seal) to 26  $k\Omega$ . This of no consequence, particularly since mercury when added will drop resistance to very low value, anyway.

With the 6 amps (about) through the carbon brushes with the cylinder and disc shorted out, noted about a 4-volt drop across the carbon brushes. This would be the drop across all four brush sets in series.

At this point there was a main power failure on the station. Secured for the day. It does appear there will be a problem in determining the drop across the mercury brush alone.

During actual conduct of test with mercury, carbon, brush drop will be that of only two brushes.

rotated 180° in the vertical plane.

The test was conducted at a constant rate of 10°/min.

The test was conducted at a constant rate of 10°/min.

(1) The test was conducted at a constant rate of 10°/min.

on the test (see Fig. 1).

Load was applied to the test (see Fig. 1).

Started at 10° and rotated to 180°.

(about 4,000 rpm) and the test was conducted at a constant rate of 10°/min.

as yet no change in the test results was observed.

don't see any change in the test results.

from the test results (see Fig. 1).

rotational speed was increased to 10,000 rpm.

rotator. In practice with the test results.

rotational speed was increased to 10,000 rpm.

greater (see Fig. 1).

tion (see Fig. 1).

very low value, see Fig. 1.

With the test results (see Fig. 1).

rotation was increased to 10,000 rpm.

rotation was increased to 10,000 rpm.

at 10,000 rpm (see Fig. 1).

at 10,000 rpm (see Fig. 1).

station, located for the test.

be a good test for the test.

brush, see Fig. 1.

rotation of the test results.

rotation of the test results.

1 MAY 1952

Installed voltage probes, ~~as shown by sketch on Page 36~~. Some adjustment appears necessary: voltage fluctuates  $\pm .2v$ . May be due to carbon brush irregularities. Still have not used mercury, although obtained 5# jug of Hg and funnel and graduate from Professor Reynolds of Chemistry Department.

Device ran satisfactorily--was on only 10-15 minutes. Ran current up to about 12 amps; brass slip rings may develop a squeal and they seemed to get quite hot for such a short run.

Believe voltage probes will be satisfactory. Next plan to run in carbon brushes for an hour or so.

2 MAY 1952

Voltage probes proved unsatisfactory; marked tendency to cut into shaft.

3 MAY 1952

Tried brass spring leaf bearing on brass slip ring. Might be satisfactory if spring leaves were longer; riding on edge (side) of slip rings, there is too much relative velocity. Electrician's Mate 1/C Hall suggested use of twin-brush recorder to permit comparison voltage fluctuations due to carbon brushes and those due to brass spring leaf contacts. Set up brush apparatus but did not have time to make it function properly.

1 MAY 1952

Indicated voltage was 100 V. Some slight variation in voltage was observed. - 2v. may be due to a small amount of leakage. Have not used battery, but have used tunnel and ready-to-go. (The voltage is 100 V. Department.)

Device can withstand -- as on only 100 V. Man current up to about 10 V. Developed a special circuit for such a short run. Believe voltage would be 100 V. plan to run in such a manner for 100 V.

2 MAY 1952

Voltage was 100 V. to cut into shift.

3 MAY 1952

Try to see if the device will withstand 100 V. Might be satisfactory if the device is 100 V. on edge (edge of film strip). Velocity. (Estimated 100 V. twin-beam response to 100 V. due to 100 V. on pressure. But no direct evidence. (The voltage is 100 V.)

There is a fair amount of random voltage fluctuation across the carbon brushes; there is even more across the brass springs. At this point it appears steady voltages will not be attainable. Possibly a better fit of the carbon brushes will reduce the fluctuations.

7 MAY 1952

Removed stiff brass voltage pickoffs and replaced with longer, less-stiff, brass spring leaf pickoffs. Made it possible to reduce relative velocity at point contact by moving this point closer to center of rotation. Still, however, had voltage fluctuations  $\pm 0.4$  volt on a 2-volt max. Sanded contacts and brass slip-ring. Also re-sanded one set of carbon brushes. Not much effect.

Decided to fill contact race with carbon smudge from the slip-ring--there was an immediate reduction to negligible proportions of the voltage swing about a stable value. This stability resulted for both voltages: that taken from the slip-ring and that taken across the entire carbon brush assembly in series. With the arrangement for the brush run-in (all four sets in series), the voltmeter on the slip-rings was reading the drop across the two center sets of the series. It should have, therefore, read  $\frac{1}{2}$  the voltage across the entire set, which it did to a reasonable degree. A maximum current of about 10-12 amperes was put through the four carbon brush sets in series for about two hours. It was observed that the brush drop was largely independent of current and somewhat of speed, rising somewhat

There is a fairly good correlation between the two series. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

## 2. MAY 1952

Removal of the effect of the correlation between the two series is possible. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

moving the correlation coefficient to 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

however, the correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

max. correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

one set of correlation coefficients. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

adjusted to 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

the adjusted correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

negligible correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

value. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

taken from the adjusted correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

carbon is the correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

the correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

on the adjusted correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

sets of the series. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

voltage. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

degree. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

through the correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

hours. The correlation coefficient is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.

degree of correlation is 0.85. The correlation is significant at the 1% level. The correlation is significant at the 1% level.



with speed. It was also observed that the driving motors slowed down when current through the brushes was reduced or interrupted, coming quickly up to original speed when current was again turned on. The effect was an immediate and easily noticeable one.

The device was run up to about 6,000 rpm on each end for several minutes at a time. It is believed alignment, lubrication, stability, control, rigidity, temperature rise are now satisfactory for actual test runs with mercury.

The fluid brush shunt was removed; strobotacs, voltmeters, ammeter, etc. were made ready. Next plan to add mercury and record data. Be sure to provide two ventilating fans.

8 MAY 1952

Poured 10 cc. of Hg into cylinder. Measured resistance (about 30 ohms). Started rotation, relative velocities up to several thousand rpm. Resistance variable, but very much greater than 30 ohms. It appeared after several minutes of rotation that the resistance was almost that of an open circuit. After several minutes of rotation, although the shaft thermometers were steady at about 45°C, the cylinder was almost too hot to touch.

On the idea that there was insufficient area of contact due to rotation holding the Hg on the inside periphery of the cylinder and away from the disc, 5.5 cc. more of Hg were added to the cylinder. This dropped the static re-

with some of the other specimens. The specimens were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color.

The specimens were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color.

## 2 MAY 1932

Porter No. 10. The specimens were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color. They were all of the same size and shape, and were all of the same color.

sistance to about 20 ohms, but appeared to have no effect in reducing the dynamic resistance. Again, high heat was noted on the cylinder perimeter with cool shafts.

It is possible there was enough oil film in the cylinder to cause an insulating effect. (There was no cleaning fluid available in the lab upon assembly to remove all oil.) It is possible there will be slight amalgamation with time, sufficient to break down the high resistance effect. It is also possible that introduction of a fairly heavy current through the brush will reduce the high resistance.

It was noted that the cylinder motor came up to speed much more easily with the disc motor off, indicating a good deal of friction between the low carbon steel and the mercury.

No leaks were noted. Cylinder was secured with filler plug down to test for leaks overnight.

Next plan to shift pulleys such that can have very low rpm on disc and cylinder--possibly introduce current next time.

9 MAY 1952

No Hg leakage overnight. Shifted to low speed pulleys. Static resistance about 25 ohms. Ran the device, turned brush current on. Used varying amounts of current up to 12 amps. Carbon brush drop fairly steady at about 2-2.5 volts; mercury drop steady--.15-.5 (fluctuates). Stopped device, measured static resistance (about 2 ohms). Upon letting machine set idle for 10-15 minutes, static

resistance.

It was noted that the information was not to be used for any other purpose than the one for which it was provided. The information was to be used for the purpose of the investigation only and was not to be disclosed to any other person without the express written consent of the Director of the FBI.

2 MAY 1962

resistance built back up to 25 ohms. There is an immediate drop in resistance once current is turned on and the resistance is variable such that the voltage drop is constant and independent of current. Voltmeter fluctuations are believed to be caused by imperfect voltage pick-offs and carbon brush contacts. Plan next to take data.

#### 12 MAY 1952

Some Hg leakage, 1 drop, due to loose pressed paper insert between disc shaft and cylinder. Tightened two hold-on screws; (should have had four or more of these screws.) Estimate now have about 15.5, (.3, .4) cc. Hg in cylinder.

Measured static resistance, 16 ohms. Ran device without current; measured static resistance again, 3.5 ohms. Device still exhibits immediate resistance drop when current turned on; voltage drop still independent of current.

Took data, listed as Test No. 1. The "average" column is not necessarily the arithmetic average of the maximum and minimum readings, but is rather the value at which the needle appeared to want to indicate. Each reading consumed about 5 minutes in order to permit something approaching "steady-state."

#### 14 MAY 1952

Ran tests No. 2 through 4. Brush current up to 48 amperes; relative rpm up to 1400.

#### 15 MAY 1952

Ran tests No. 5 through 7. Current up to 48 amps;



relative rpm up to 2500. Voltage drop across carbon and mercury remain largely independent of current but shows slight increase (.2 volt) as the temperature rises to 100°C. One hundred degrees C. has been taken as an arbitrary upper limit since this temperature is being read at the center of the Hg brush, whereas the hot-spot seems to be on the cylinder periphery. Care is being taken to avoid flashing the mercury into poisonous vapor which would occur if the Hg temperature were to rise to 357°C, STP. All bearings run cool to the touch. The brass slip rings are too hot to touch, as is the cylinder.

#### 16 MAY 1952

Ran Tests No. 8 and 9, (48 amps, 3500 rpm). Limited to 48 amps by current density of carbon brushes. Carbon brush contact surface is

$$4 \times \frac{5}{16} \times \frac{3}{4} = \frac{60}{64} \text{ in.}^2 ; \quad \frac{48 \text{ amps}}{60/64} = 50 \text{ amps/in.}^2$$

Actually, I believe mercury can carry much greater currents with proper cooling provided. Have not computed Hg current density, but believe it to have reached only some 5 to 10 amps/in.<sup>2</sup>

#### 17 MAY 1952

Conducted no formal tests, but ran device at about 3,000 rpm, relative and 5 amps from about 1030 steadily until 1630 (6 hrs.) as part of Armed Forces Day exhibit.

relative humidity of 75% at 100°F. The  
 humidity was maintained at 75% by means of  
 slight increase (1.5 psi) in the pressure.  
 One hour after the start of the test the  
 first trial was made. The test was  
 the 10th trial, when the test was  
 not possible. The test was  
 mercury in a polarized position. The  
 temperature were 100°F. The test was  
 cool to 100°F. The test was  
 touch, as in the test.

# 12 MAY 1971

The data was 100°F. The test was  
 48 were the current data of 100°F. The test was  
 contact was 100°F.

$$\frac{1}{V} = \frac{1}{V_0} + \frac{1}{V_1} \quad ; \quad \frac{1}{V} = \frac{1}{V_0} + \frac{1}{V_1}$$

The data was 100°F. The test was  
 current data was 100°F. The test was  
 18 current data was 100°F. The test was  
 some 100°F.

# 12 MAY 1971

The data was 100°F. The test was  
 100°F. The test was  
 100°F. The test was



Temperature cylinder about 55°C.; discs, 60°C; carbon voltage about 3.2v; Hg voltage about 0.5 v all day. Both voltages steady.

19 MAY 1952

One drop of Hg leakage. Estimate 15 cc. Hg still in cylinder. Static resistance equals 40  $\Omega$ ; dynamic R = 5 $\Omega$ . Ohmmeter Weston Model 665, type 3, Serial 041058. Ambient 27°C.

Ran tests No. 10 through 15. Noted disc end becoming quite hot and noted in connection with it that pressed paper insert around shaft at cylinder (mercury seal) seemed to be binding on shaft. Again used up to 48 amps, rpm up to 6,000 with 6,500 rpm for a short duration. Greased seal again.

Also noted cylinder slinging Hg through threaded joint, apparently as a result of heat expansion and centrifugal force at 3,000 rpm. Estimate 14.5 cc. of Hg remaining in cylinder.

Indications are that tests should possibly be at test rpm and maximum current (48 amps) from a cold start with ~~them~~ then a temperature-time curve taken to estimate how close to temperature stability device is approaching before one or other of thermometers reach 100°C.

Temperature of the liquid about 100°C; voltage about 0.15 V; current about 0.1 A; steady.

## 19 MAY 1952

One run of the test was made. The test was made with the test cell at 100°C; voltage about 0.15 V; current about 0.1 A; steady.

At the end of the test, the test cell was cooled to about 20°C. The test was then repeated with the test cell at 20°C. The test was made with the test cell at 20°C; voltage about 0.15 V; current about 0.1 A; steady.

At the end of the test, the test cell was cooled to about 20°C. The test was then repeated with the test cell at 20°C. The test was made with the test cell at 20°C; voltage about 0.15 V; current about 0.1 A; steady.

Indications are that the test was made with the test cell at 20°C. The test was made with the test cell at 20°C; voltage about 0.15 V; current about 0.1 A; steady.

20 MAY 1952

Started device; temperature on disc end jumped to 70°C. Packed grease about pressed paper seal. Secured after a 5-minute run. No leakage apparent. Static resistance on order of 20-40 ohms; ohm meter appeared unstable.

21 MAY 1952

Ran tests No. 16, 17, 18. One drop leakage. Where greasing was of some help, effect quickly wore off at 3500 rpm and disc end again began to show excessive temperature. Repacked seal with grease.

22 MAY 1952

Assisted Prof. Polk in calibrating voltmeters used to obtain carbon and mercury drops; meters very good.

23 MAY 1952

Ran Test No. 19. First assisted Prof. Polk in calibrating ammeter used to obtain brush current; both accurate to high degree.

Reversed polarity on brush; i.e., made disc (+), cylinder (-). Also reduced carbon brush pressure to the minimum. Drive belts appear to be showing effect of wear. Still have binding at pressed-paper insert causing excessive heating.

24, 25 MAY 1952

Reducing data, drawing curves, computing.



Calculated minimum Hg contact surface; found it to be 6.11 in.<sup>2</sup> compared to only 15/16 in.<sup>2</sup> for carbon. Maximum Hg density (48 amps) = 7.85 amp/in.<sup>2</sup> compared to 51.15 amp/in.<sup>2</sup> for carbon. <sup>de</sup>Conclusions have been ultra-conservative. Calculations suggest removal of Hg to point just where no leakage can occur on the shaft opening,--the less Hg, the less heat due to friction.

In this connection, also remove paper insert and cut off its flange since ~~it~~ will have no leakage problem, except that seeping through threaded joint. Also solder a bead about the open threads at the shaft side of the cylinder. The combination of drilled core and threads have reduced shaft c/s area at this point to the extent where a hot-spot develops at currents above 40 amps.

Believe above three steps may make possible 10,000 or 12,000 rpm without excessive heating. Also, since load bank will handle 72 amps and DC generator is rated at 59 amps (110v), believe can go to highest available current.

26 MAY 1952

Cut down seal but had to add back some tape to stop Hg slinging. Reduced mercury level to 1 7/32" (1 15/64") above bottom of cylinder exterior. RPM 4,000 each end with no excessive heating. Put solder bead about exposed threads on shaft at cylinder.

Next try reducing Hg level to bottom of exterior seal. Amounts to a reduction of 2cc. from above.

The following table shows the results of the analysis of variance for the effect of the concentration of the solution on the rate of reaction. The data are given in the following table:

Concentration of solution (M)	Rate of reaction (1/min)
0.01	0.001
0.02	0.002
0.03	0.003
0.04	0.004
0.05	0.005
0.06	0.006
0.07	0.007
0.08	0.008
0.09	0.009
0.10	0.010

The results show that the rate of reaction increases linearly with the concentration of the solution. This is in agreement with the theoretical prediction that the rate of reaction is proportional to the concentration of the reactants.

[illegible]

100

1. The first step is to identify the problem. This involves understanding the situation and the goals that need to be achieved. It is important to gather all relevant information and to consider the perspectives of all stakeholders involved.

Threw out enough Hg in running @ 10,000 rpm to place Hg level at bottom of seal exterior by coincidence. Prior to shutting down after Test 22 noted Hg drop as low as .05v with 5 amps, 3,000 rpm each end.

In then attempting to go to 6,000 rpm on each end, encountered excessive vibration and Hg slinging to point where open-circuit developed across mercury brush. Re-filled cylinder to 1 15/64" above bottom of cylinder exterior, and conducted Test No. 23.

At 1600, thermometer in cylinder shaft (tape) came loose and was bent. Straightened; have next to test this thermometer for accuracy in any future tests.

Stopped driving motors; allowed 5 amps. to flow; drop across Hg brush fluctuated 0.4v to 1.1v.

Perhaps possible to conclude mercury is satisfactory as an electrical brush at high rpm (peripheral velocities) if the amount of Hg is kept to a minimum. Course now suggested is to weld threaded joint and to add four more screws or so on seal to obviate any leakage, then fill to Hg level used in 10,000 rpm test. (Hg level 7/8" above bottom exterior of cylinder) and then run device at maximum current (48 or 59 amps) for 1,000 hours or until failure. At this point, remove weld, disassemble, examine for condition of surfaces and of Hg and also amount of Hg left. If still satisfactory, reseal and reweld and run for 1,000 more hours in an altitude chamber.

[illegible]



APPENDIX B

Excerpts From Liquid  
Metals Handbook

10. 10. 1944

Experiments with light

Method of measurement

Ref: Liquid Metals Handbook, NavExos P-733, 1 June 1950,  
Atomic Energy Commission, Department of the Navy,  
Washington, D. C. For sale by Superintendent of  
Documents, U.S. Government Printing Office,  
Washington, D. C. \$1.25

Page 2: "The pressure created by passing an electric current through a molten metal, in combination with a magnetic field, offers a solution to the problem of pumping these metals." (i.e., molten Al, Zn, Cu, etc.) Pumping head only 1 to 2 feet (p. 5).

Page 5: The present (1950) uses of liquid metals do not list electric current conduction through a moving contact.

Page 9: Hg boiler tubes are made from Sicromo 5S steel (0.12 C, 0.5 Mo, 5.0 Cr, 1.5 Si) which has a very low solubility in Hg. The use of .000005 to .001 per cent *titanium* and .002 per cent Mg in the Hg assures that Hg wets steel and reduces solubility of tube metal (9500-10500 F). 18-8 stainless also good.

Page 11: "A pipe filled with Na was used as a bus bar for carrying 4000 amps of DC current by Dow Chemical CO." (See Boundy, R. H., Trans. Electrochem. Soc. 62, 151 (1932), Sodium Bus Bar--A 4000 amps. cond. "Liquid metals are successfully used as 'brushes' in electrical equipment."

Page 12: "Metals are elementary substances and do not

[illegible]

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

to the *in vitro* activity of the *in vivo* actinides

[illegible]

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 2222 2223 2224 2225 2226 2227 2228 2229 2230 2231 2232 2233 2234 2235 2236 2237 2238 2239 2240 2241 2242 2243 2244 2245 2246 2247 2248 2249 2250 2251 2252 2253 2254 2255 2256 2257 2258 2259 2260 2261 2262 2263 2264 2265 2266 2267 2268 2269 2270 2271 2272 2273 2274 2275 2276 2277 2278 2279 2280 2281 2282 2283 2284 2285 2286 2287 2288 2289 2290 2291 2292 2293 2294 2295 2296 2297 2298 2299 2300 2301 2302 2303 2304 2305 2306 2307 2308 2309 2310 2311 2312 2313 2314 2315 2316 2317 2318 2319 2320 2321 2322 2323 2324 2325 2326 2327 2328 2329 2330 2331 2332 2333 2334 2335 2336 2337 2338 2339 2340 2341 2342 2343 2344 2345 2346 2347 2348 2349 2350 2351 2352 2353 2354 2355 2356 2357 2358 2359 2360 2361 2362 2363 2364 2365 2366 2367 2368 2369 2370 2371 2372 2373 2374 2375 2376 2377 2378 2379 2380 2381 2382 2383 2384 2385 2386 2387 2388 2389 2390 2391 2392 2393 2394 2395 2396 2397 2398 2399 2400 2401 2402 2403 2404 2405 2406 2407 2408 2409 2410 2411 2412 2413 2414 2415 2416 2417 2418 2419 2420 2421 2422 2423 2424 2425 2426 2427 2428 2429 2430 2431 2432 2433 2434 2435 2436 2437 2438 2439 2440 2441 2442 2443 2444 2445 2446 2447 2448 2449 2450 2451 2452 2453 2454 2455 2456 2457 2458 2459 2460 2461 2462 2463 2464 2465 2466 2467 2468 2469 2470 2471 2472 2473 2474 2475 2476 2477 2478 2479 2480 2481 2482 2483 2484 2485 2486 2487 2488 2489 2490 2491 2492 2493 2494 2495 2496 2497 2498 2499 2500 2501 2502 2503 2504 2505 2506 2507 2508 2509 2510 2511 2512 2513 2514 2515 2516 2517 2518 2519 2520 2521 2522 2523 2524 2525 2526 2527 2528 2529 2530 2531 2532 2533 2534 2535 2536 2537 2538 2539 2540 2541 2542 2543 2544 2545 2546 2547 2548 2549 2550 2551 2552 2553 2554 2555 2556 2557 2558 2559 2560 2561 2562 2563 2564 2565 2566 2567 2568 2569 2570 2571 2572 2573 2574 2575 2576 2577 2578 2579 2580 2581 2582 2583 2584 2585 2586 2587 2588 2589 2590 2591 2592 2593 2594 2595 2596 2597 2598 2599 2600 2601 2602 2603 2604 2605 2606 2607 2608 2609 2610 2611 2612 2613 2614 2615 2616 2617 2618 2619 2620 2621 2622 2623 2624 2625 2626 2627 2628 2629 2630 2631 2632 2633 2634 2635 2636 2637 2638 2639 2640 2641 2642 2643 2644 2645 2646 2647 2648 2649 2650 2651 2652 2653 2654 2655 2656 2657 2658 2659 2660 2661 2662 2663 2664 2665 2666 2667 2668 2669 2670 2671 2672 2673 2674 2675 2676 2677 2678 2679 2680 2681 2682 2683 2684 2685 2686 2687 2688 2689 2690 2691 2692 2693 2694 2695 2696 2697 2698 2699 2700 2701 2702 2703 2704 2705 2706 2707 2708 2709 2710 2711 2712 2713 2714 2715 2716 2717 2718 2719 2720 2721 2722 2723 2724 2725 2726 2727 2728 2729 2730 2731 2732 2733 2734 2735 2736 2737 2738 2739 2740 2741 2742 2743 2744 2745 2746 2747 2748 2749 2750 2751 2752 2753 2754 2755 2756 2757 2758 2759 2760 2761 2762 2763 2764 2765 2766 2767 2768 2769 2770 2771 2772 2773 2774 2775 2776 2777 2778 2779 2780 2781 2782 2783 2784 2785 2786 2787 2788 2789 2790 2791 2792 2793 2794 2795 2796 2797 2798 2799 2800 2801 2802 2803 2804 2805 2806 2807 2808 2809 2810 2811 2812 2813 2814 2815 2816 2817 2818

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

- *Journal of Management Studies*, 1987, 24(6), pp. 601-617.

DATE \_\_\_\_\_ TIME \_\_\_\_\_

1. The following information is provided for the year ended 31/12/2019:

• (7) ... of ...

1. On 27 June 1977, the first (1977) to second (1978) year

Figure 1. The effect of the concentration of the inhibitor on the rate of polymerization of  $\alpha$ -methylstyrene.

• <sup>+</sup>outnos

Page 1 of 1

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

for some time.

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

$\Gamma(\mathbb{R}^n) = \Gamma(\mathbb{C}^n) = \Gamma(\mathbb{R}^n \times \mathbb{R}^n) = \Gamma(\mathbb{C}^n \times \mathbb{C}^n)$  and  $\Gamma(\mathbb{R}^n \times \mathbb{R}^n) = \Gamma(\mathbb{C}^n \times \mathbb{C}^n)$  for all  $n \geq 1$ .

02.10 2009

1987年12月15日 星期一

Figure 1. The effect of the concentration of the *Agrobacterium* suspension on the transformation efficiency of *Agrobacterium* strains.

[illegible]

Figure 1. The effect of the concentration of the  $\text{Ca}^{2+}$  solution on the rate of the reaction of the  $\text{Ca}^{2+}$  solution with the  $\text{Ca}^{2+}$  solution (1999).

[illegible]

1. *Chlorophyll a* and *Chlorophyll b* were determined by the method of Lichtenthaler and Whistler (1972).

decompose, polymerize, carbonize, etc.

Stainless steel has operated as a hot metal container at 1000°F for 1 year.

Page 79: "Mass transfer in liquid metals may be influenced by electrical effects. Transfer of dissolved elements in solid and in liquid metals under the influence of applied potentials, referred to in the literature as electrolytic diffusion, has been observed and studied quantitatively. See also Von Kreman, R., "Electrolysis of Molten Alloys," Sammlung Chemischer und Chemisch-Technischer Vortraege 28, 347-408, 1926. For example, a direct potential of 5 volts with a flow of 20 amperes for periods of less than a day resulted in transfer of microscopic amounts of carbon in gamma iron. No evidence of mass transfer by this means has been observed so far in liquid-metal-heat transfer systems although there is some evidence that application of a potential can be used to inhibit attack. See also: Barnes, A.H., Smith, F.A., Whitham, G., Direct Current Electromagnetic Pumps, ANL-4322, Oct. 25, 1947.

Markert, W., Jr., and Piotler, E. C., B & W Repr. No. ES-401-2. (Project "Baby"; NObs-34222), June 9, 1947

Markert, W., Jr., and Piotler, E. C., B & W Repr. No. ES-401-1. (Project "Baby," NObs-34222), April 17, 1947.  
Rehn, I, ANL-4029, Sept. 2 1947

"Symposium on Basic Properties of Liquid Metals" held at ANL on April 5, 1949.

deposition, only a few, and only a few.

Estimated at 100,000 to 1,000,000.

Estimated at 100,000 to 1,000,000.

Page 7: "The same is true for the other two."

For electrical effects, see also the following.

ments in solid and in liquid, of the same kind.

applied potentials, in the case of the solid.

electrolytic effects, in the case of the solid.

titration. See also the following, etc.

Molten "oil," "hydrogen," "hydrogen," etc.

Testimony of the following, etc., etc.

directly with a voltage of 100,000 to 1,000,000.

periods of less than a day, resulting in the same effect.

acoustic amounts of carbon in water, etc.

transformation of carbon in water, etc.

metal-rod, water, etc., etc., etc.

that reaction of a chemical substance, etc.

task. See also: "The following, etc., etc."

Direct current, electrical, etc., etc.

Markov, etc., etc., etc., etc., etc.

(Project "Hydrogen," etc., etc., etc.)

Markov, etc., etc., etc., etc., etc.

ES-401-1. (Project "Hydrogen," etc., etc., etc.)

Rehn, J., etc., etc., etc., etc., etc.

"Hydrogen," etc., etc., etc., etc., etc.

See also: "The following, etc., etc., etc."

See also: "The following, etc., etc., etc."

See also: "The following, etc., etc., etc."

Page 80: "Attack on steels by mercury is completely

(rate of attack less than 1 mil per year) inhibited by the addition of titanium<sup>u</sup> or zirconium<sup>u</sup>. These inhibitors were found after very extensive and expensive laboratory investigations and though possible explanations have been offered, the mechanism by which they act is not known. Where oxygen is known to accelerate attack by liquid metals, inhibitors are being sought which will tie up the oxygen as an insoluble oxide."

Page 82: "Low-carbon steels have good resistance to attack by flowing Hg below about 400°C (752°F)."

Page 85: "Attack by Hg on ferrous alloys can be reduced to negligible amounts by the addition of an inhibitor to the mercury, the best of which is Ti. In order to insure good heat transfer and to prevent excessive use of the inhibitor, it is also necessary to add a ~~melting~~<sup>wetting</sup> agent, the best of which is magnesium." See also: Hacket, H. N., "Mercury for the Generation of Light, Heat and Power," Trans. of the ASME, Oct. 1952, p. 647.

Page 86: Add to .0001-.001 per cent Ti, or .04-.02 per cent Zr.

"Copper in Hg increases its attack on low-C steel."

"In addition to an inhibitor it was found desirable to have a ~~melting~~<sup>wetting</sup> agent present in the Hg. Its function is two-fold:

[illegible]

Page 10

[illegible]

5. The following information is available for the year ended 31/12/2014:



to reduce oxides on steel surfaces so that ~~melting~~<sup>wetting</sup> and optimum heat transfer may be realized; and to react with the free oxygen, nitrogen and water vapor in the Hg in order to keep the inhibitor active. Wetting agents must, therefore, have a greater affinity for O<sub>2</sub> and N than both the inhibitor (Ti) and iron."

"Mg has been found effective as a wetting agent with no deleterious effects. Use 20 ppm."

Page 87: "Wolfram, molybden<sup>u</sup>m, chromi<sup>u</sup>um and beryllium can be considered for longtime use as containers of Hg at elevated temperatures."

Silver solder (Ag-Cu-Zn) was drastically attacked on exposure to Hg for 24 hours at 400°C."

"Carbon is negligibly soluble in Hg."

to reduce further on the basis of the fact that the  
best results may be obtained by the use of the  
geochemical and water analysis methods.  
The following are the results of the analysis:  
greater efficiency for the use of the geochemical  
analysis method.

1. The first condition is that the "need" must be "urgent".

[illegible]

9-11-1964 (11-11-1964) (11-11-1964)

1. The first step is to identify the problem or question that needs to be answered.





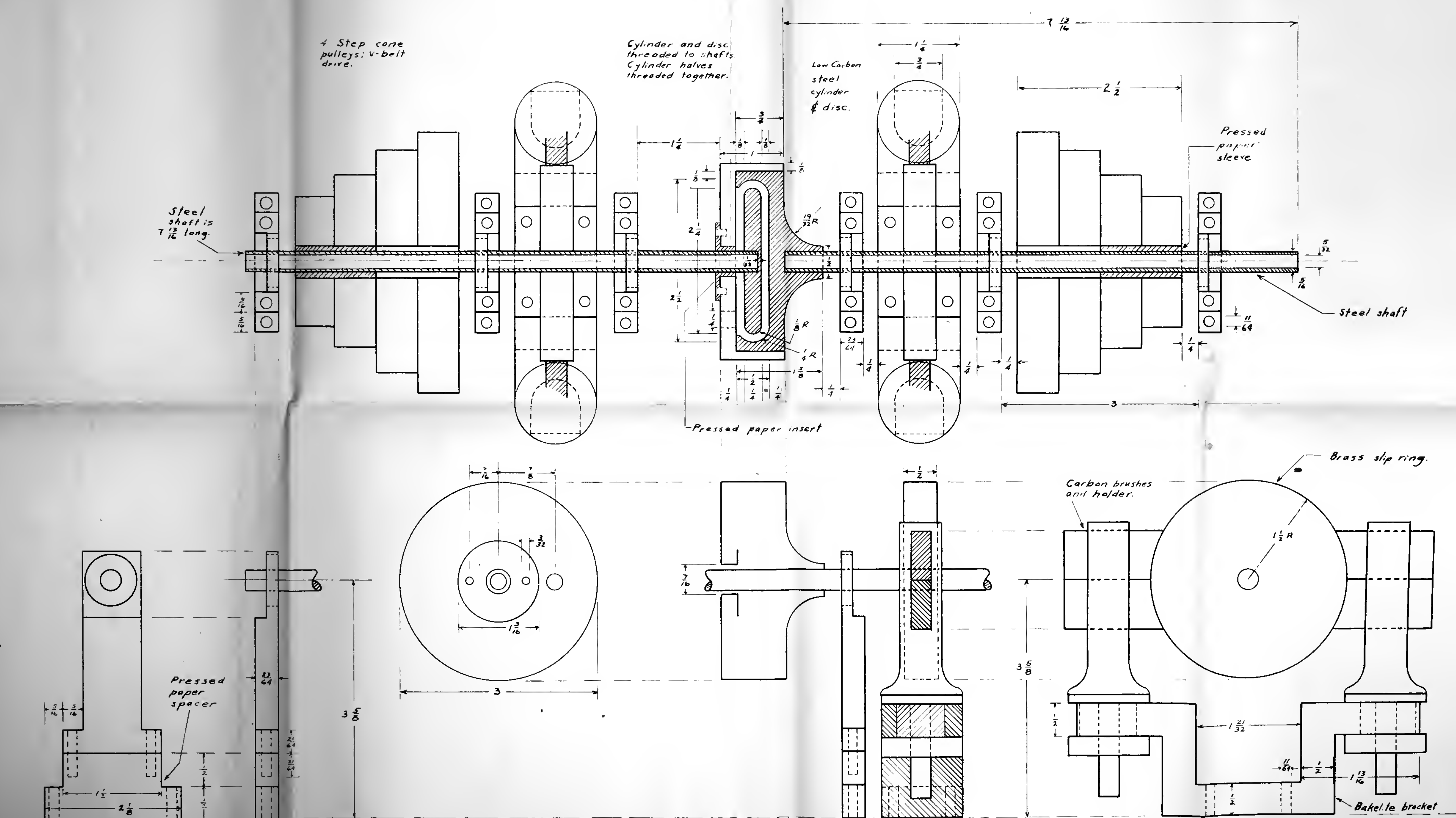


FIG. 1  
BRUSH ASSEMBLY DETAIL  
HIGH-SPEED MERCURY CONTACT  
2 June 1952 R. G. SHULTS













OCT 2  
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Shults

An investigation of mer-  
cury as a high-speed elec-  
trical contact. 1952.

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MAR 27

RENEWED

APR 10

RENEWED

MAY 19

RENEWED

JUN 5

RENEWED

NOV 23

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Shults

An investigation of mercury  
as a high-speed electrical  
contact. 1952.

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